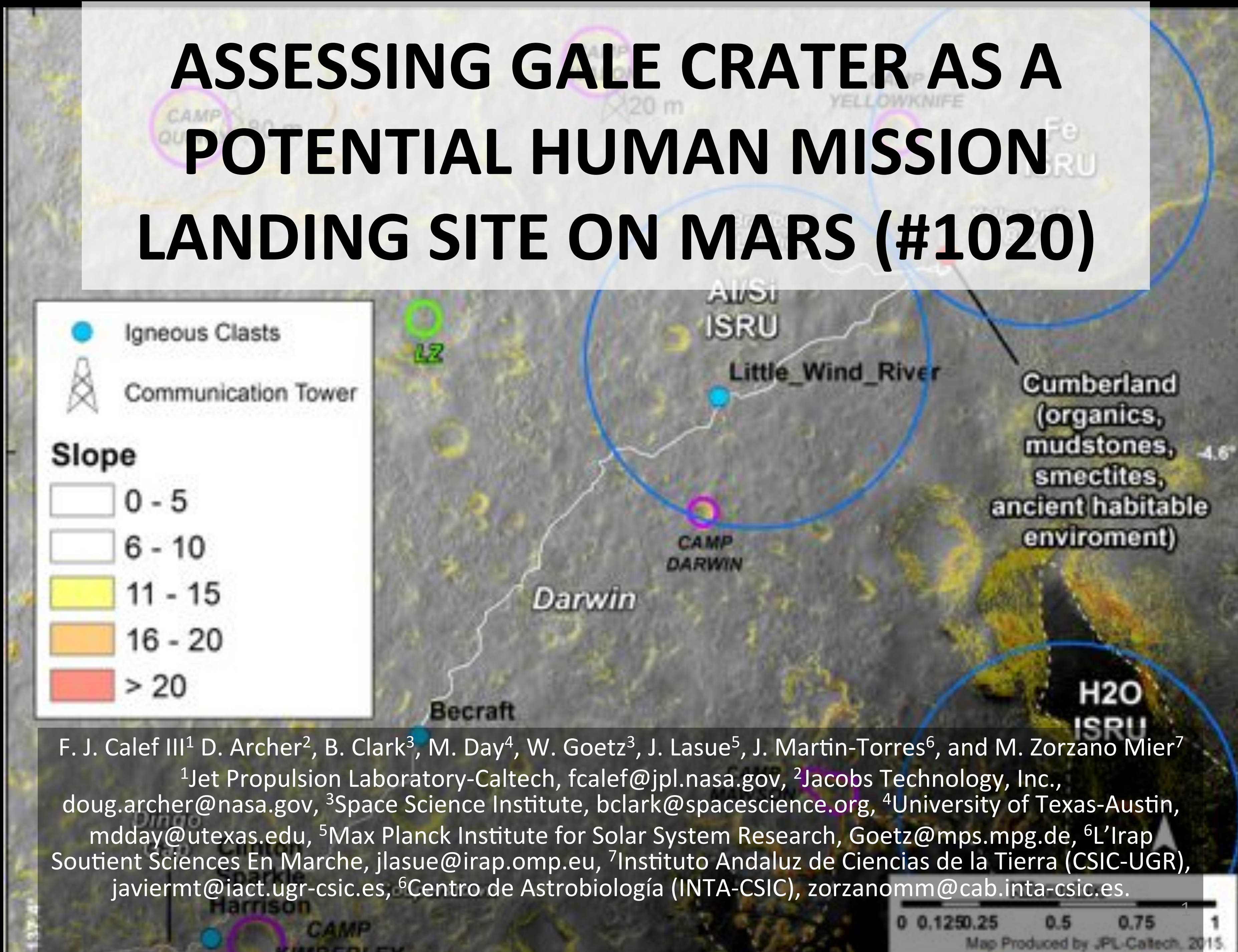
ASSESSING GALE CRATER AS A POTENTIAL HUMAN MISSION LANDING SITE ON MARS (#1020)



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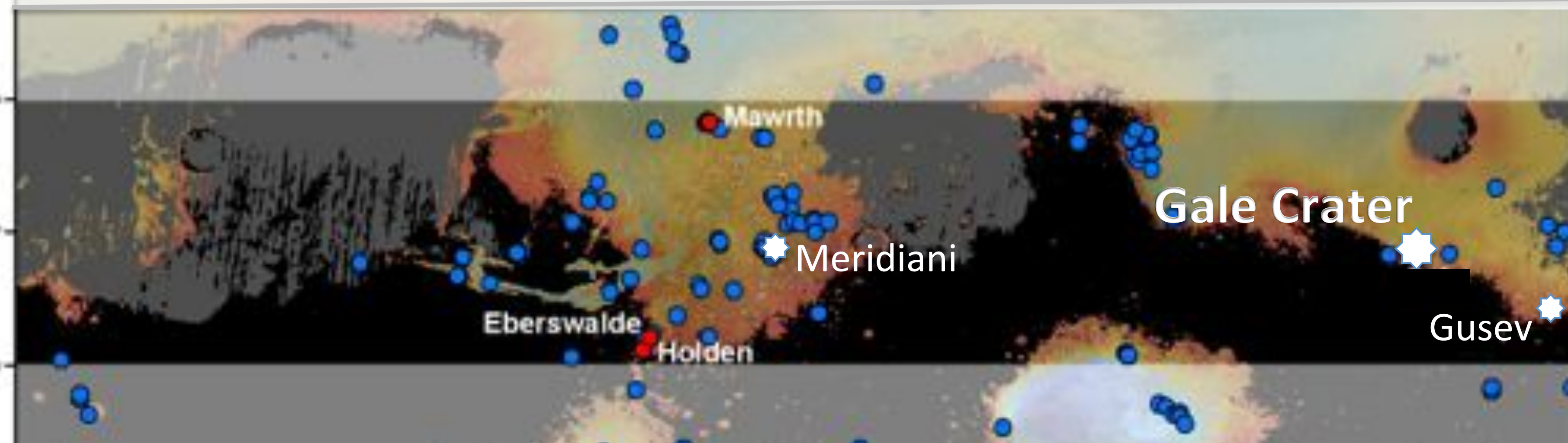
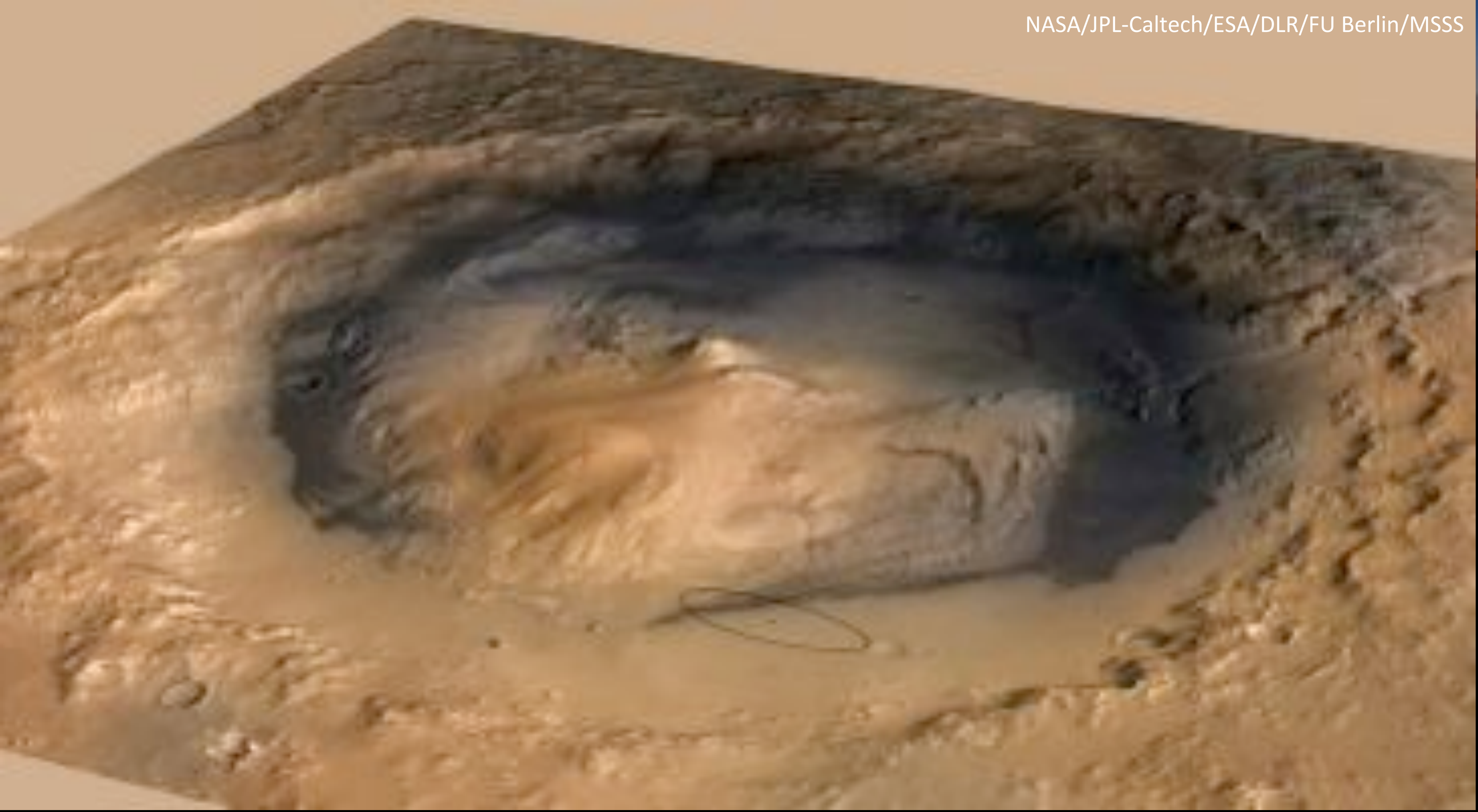
"Go Where You Know"

Three low-latitude sites with extensive ground truth exist: *Meridiani Planum*, *Gusev Crater*, and ***Gale Crater***; they offer steady climatic conditions, cm-scale hazard assessments, and well-characterized science regions of interest (ROIs).



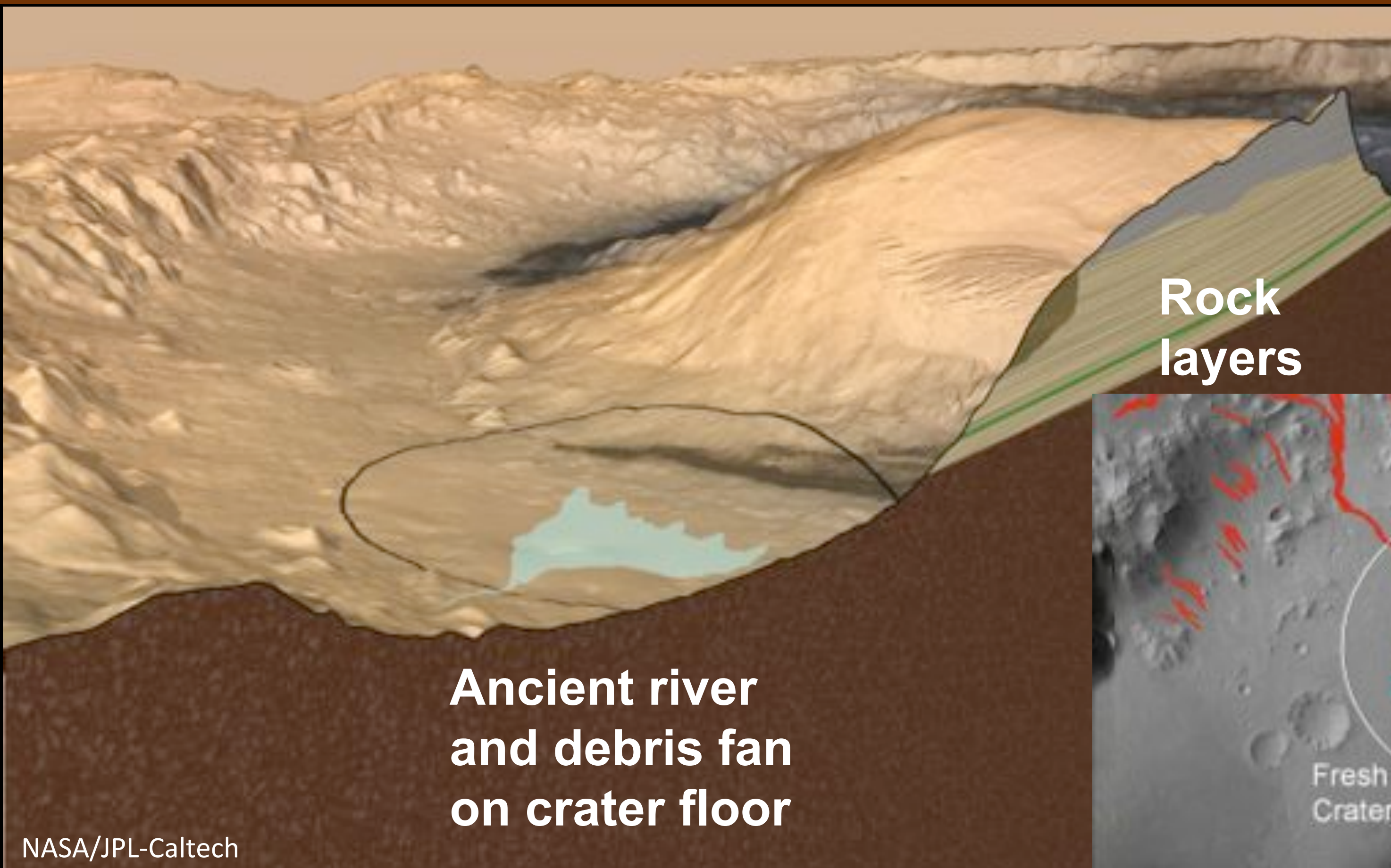
This presentation aims to show why ***Gale Crater*** offers several compelling science targets and quantified ISRU resources based on insitu observations measured from the unique set of instruments onboard the Mars Science Laboratory (MSL) rover mission.

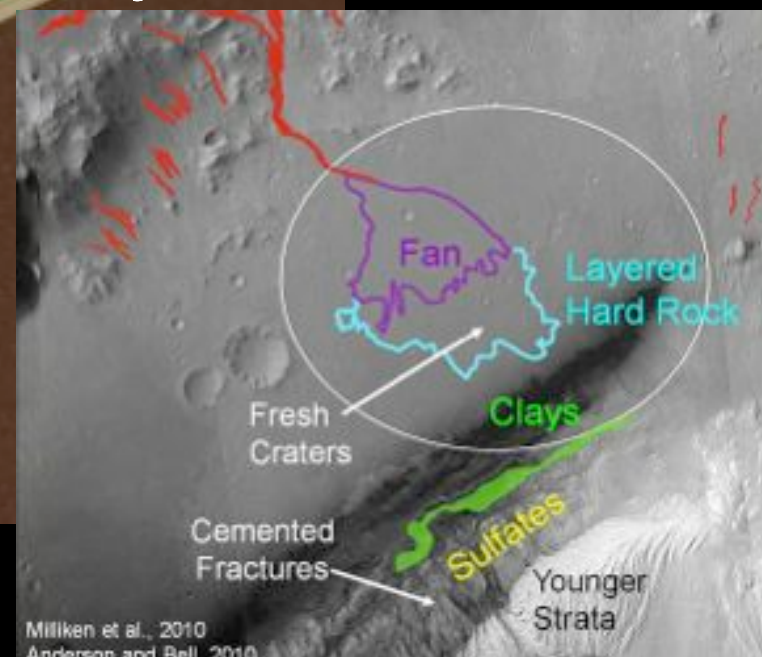


155-km Gale Crater contains a 5-km high mound of stratified rock. Strata in the lower section of the mound are composed of clays and sulfates, while the upper mound is dry, suggesting transition from ‘wet’ Mars to ‘dry’ Mars (Late Noachian to Early Hesperian?).

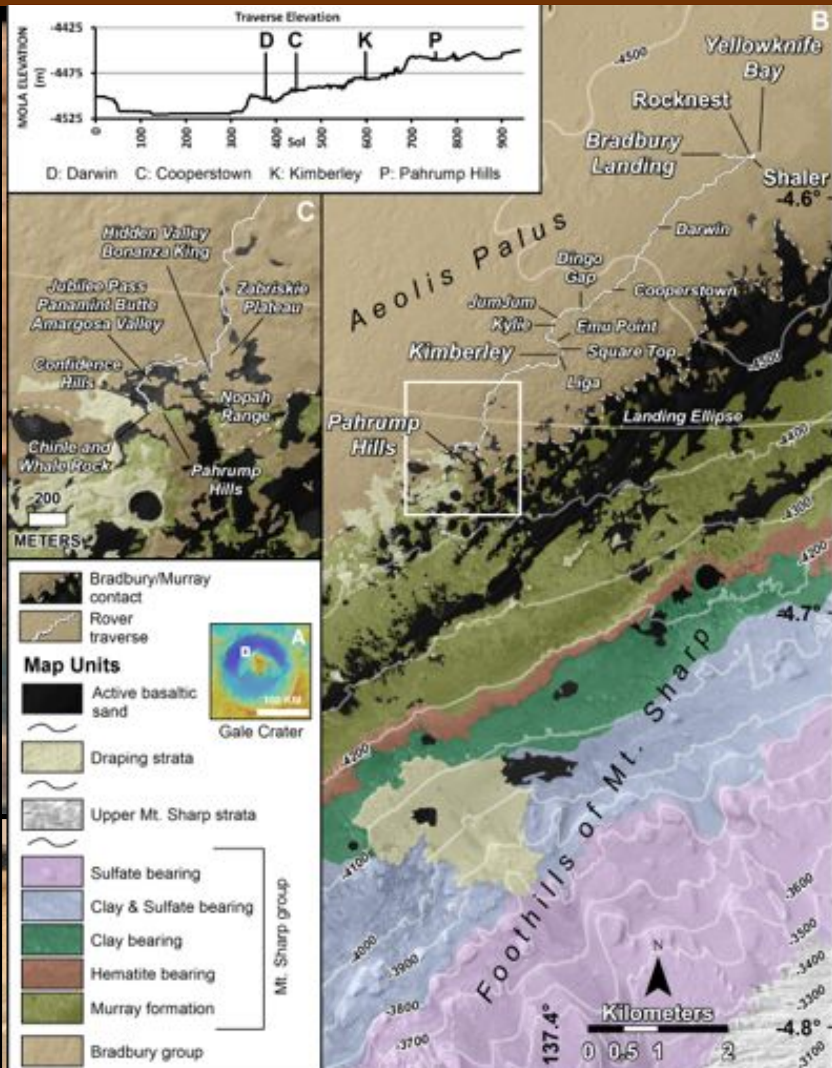
CURIOSITY

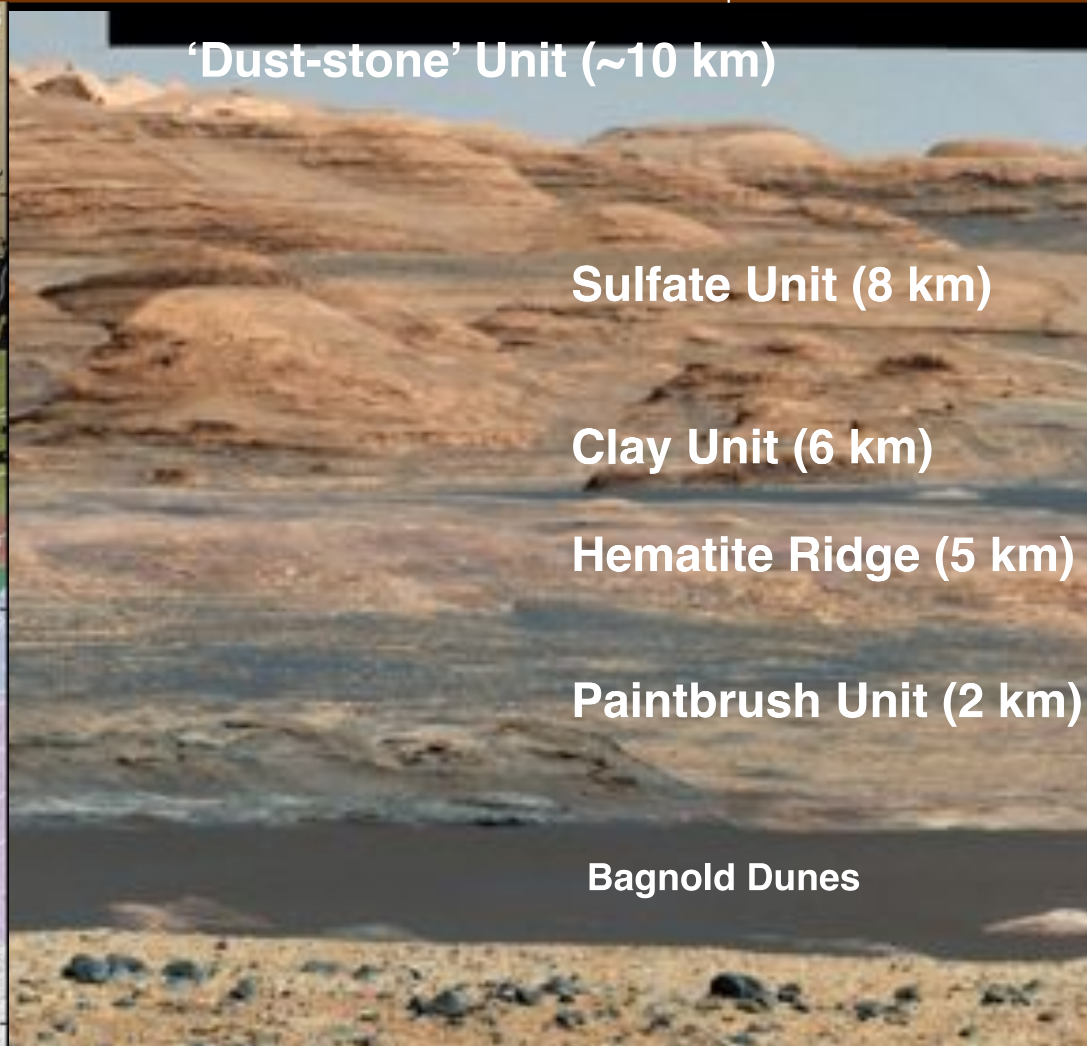
Water-Related Geology and Minerals at Mount Sharp: a 5 km Stratigraphic Record of Mars' Past





Aeolis Mons (Mt. Sharp) Geology: Transition from 'Wet' to 'Dry' Mars

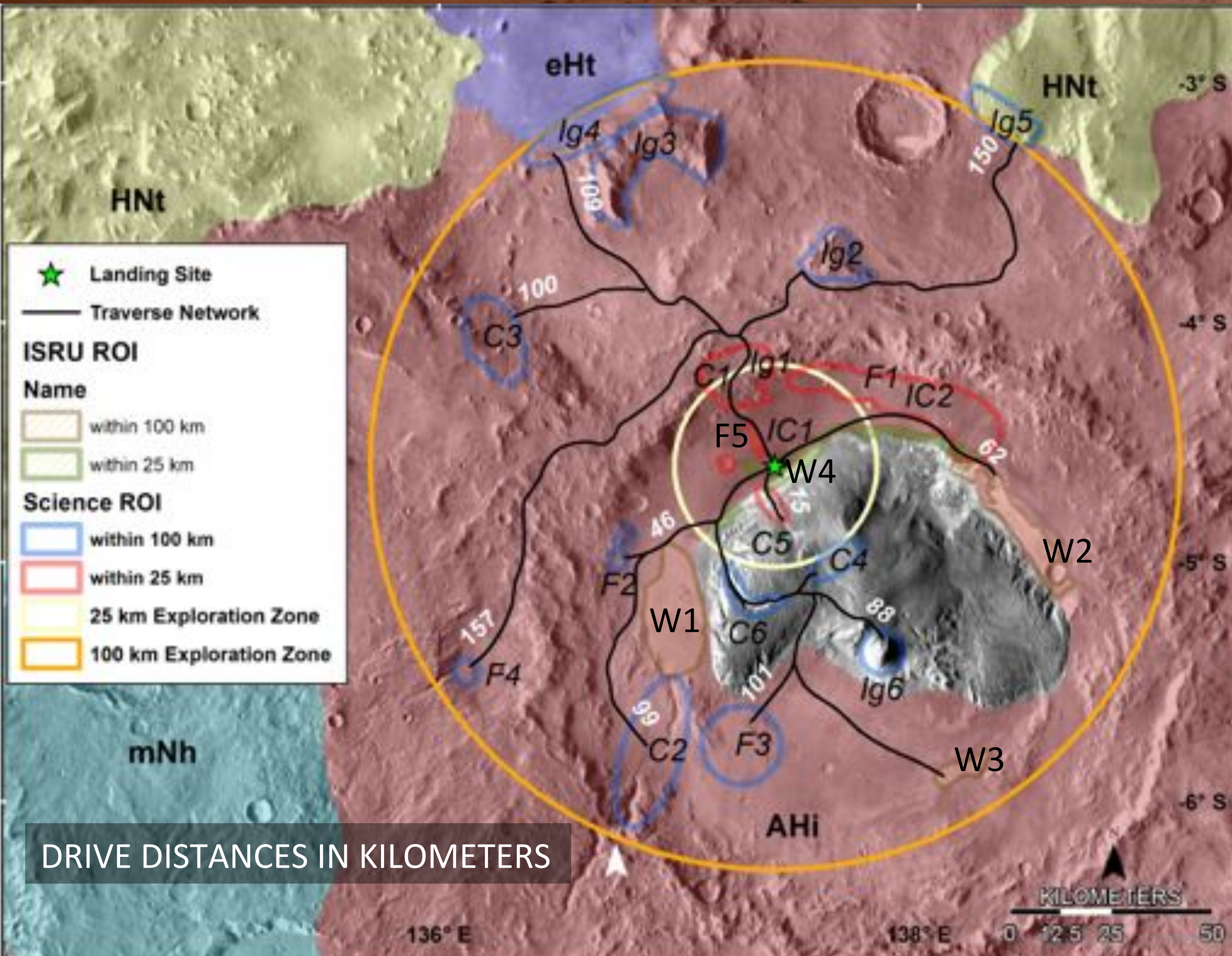




Left figure from Grotzinger et al., Science, 2015

NASA/JPL-Caltech/MSSS

Gale Crater Exploration Zone



LZ Coordinates

Longitude (E)

137.42009295°

Latitude (S)

4.59310427°

Elevation (MOLA)

-4497.77

Easting

8145534.27 m

Northing

-272254.70 m

Science ROI

C = Channel

F = Fan

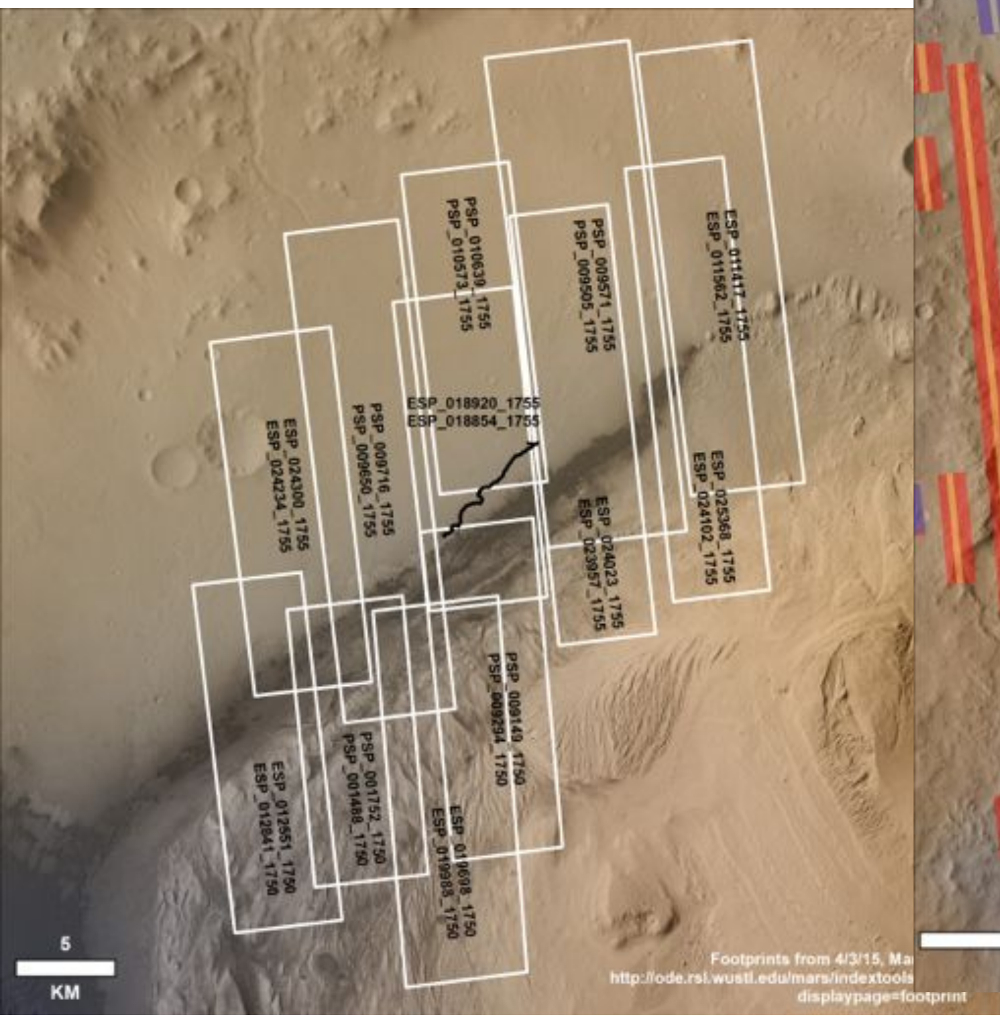
Ig = Igneous

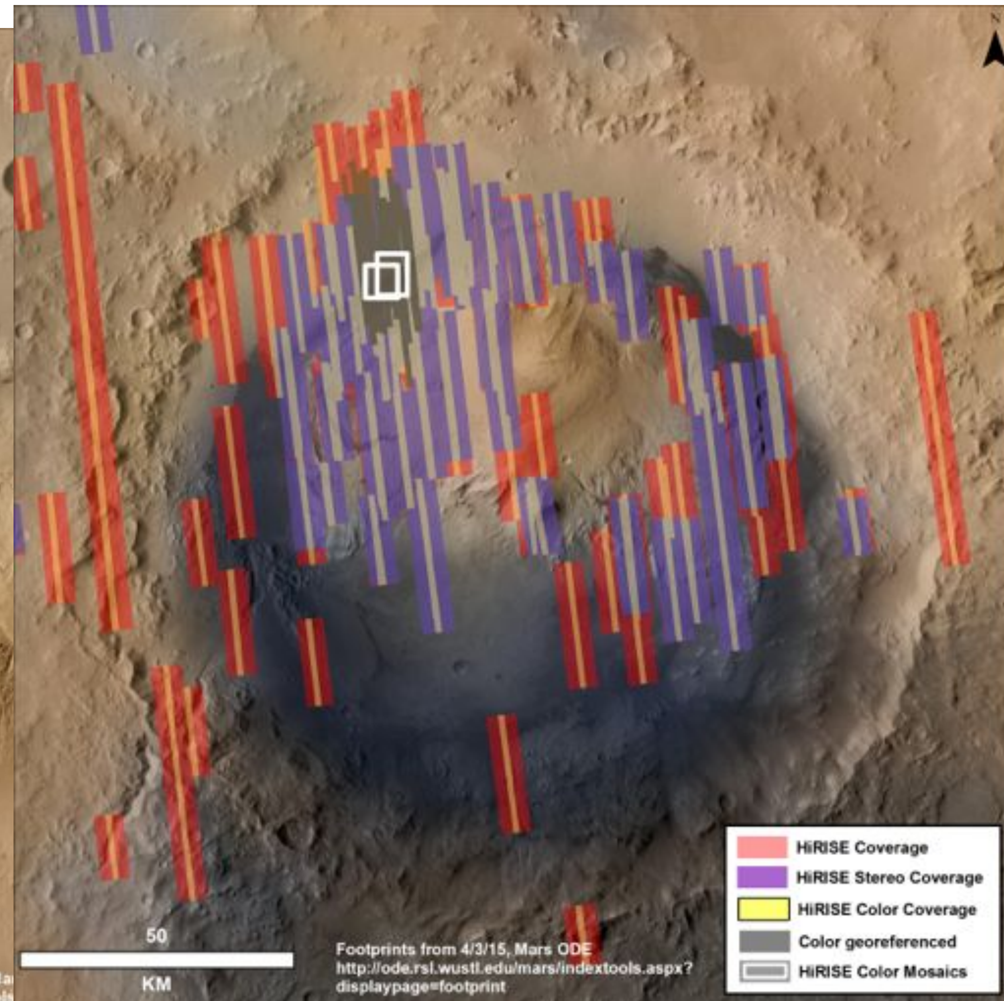
IC = Inverted Channels

ISRU ROI

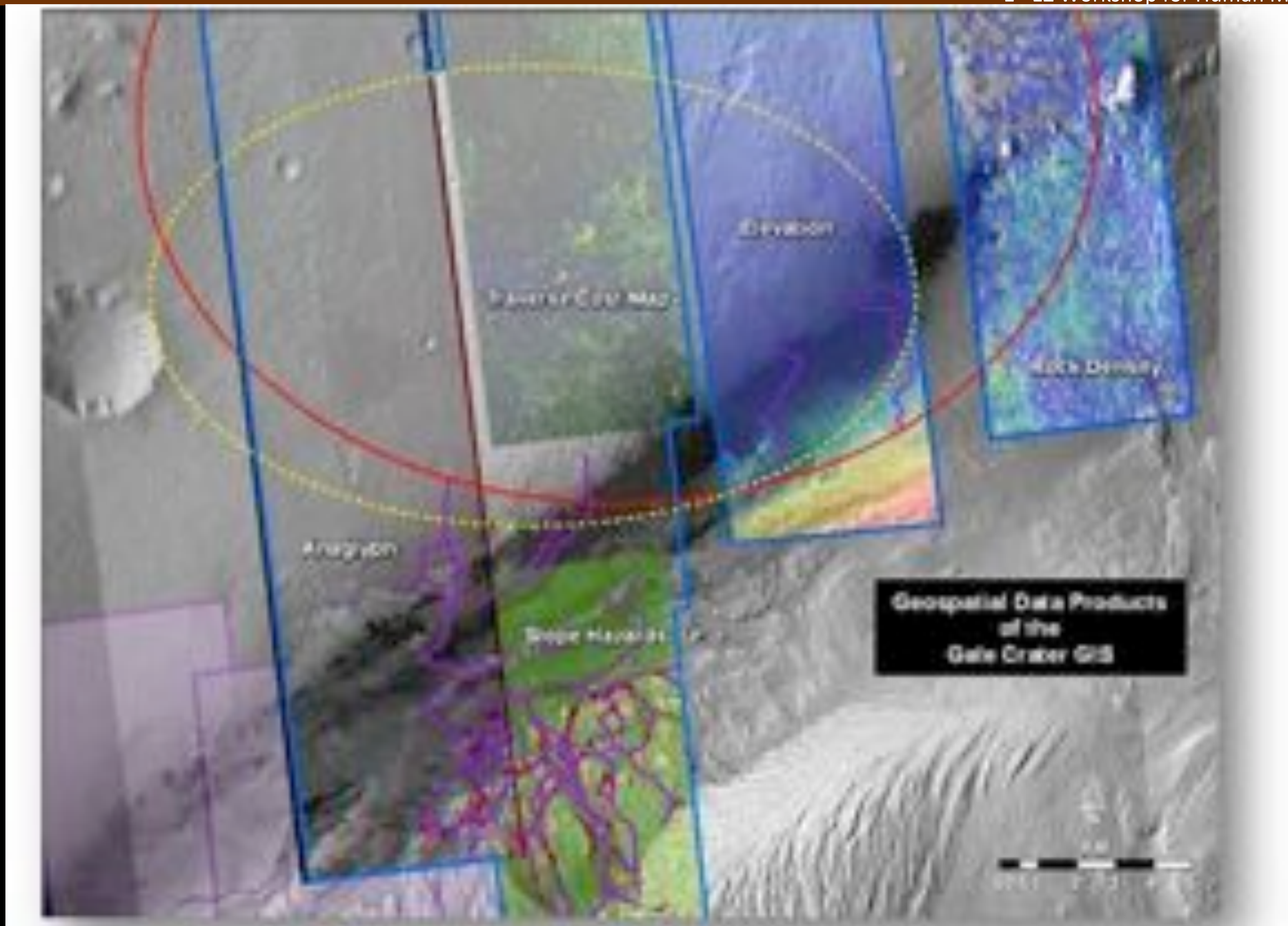
W = Water ROI

Extensive HiRISE Coverage for Analyzing Science and ISRU ROIs

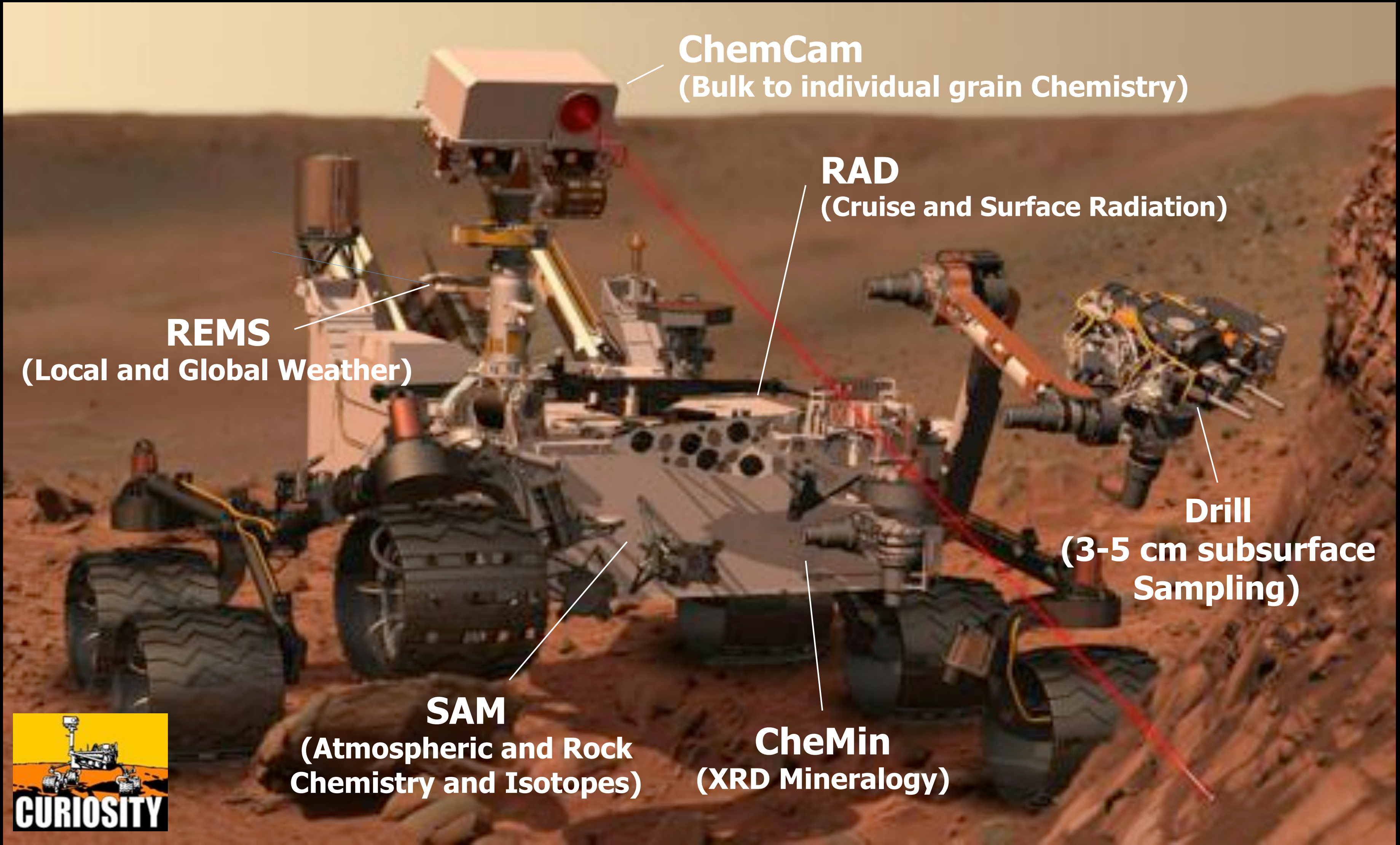




Multiple Co-Registered Datasets in Landing Zone: Slope, Rock Abundance, Hazards, and more



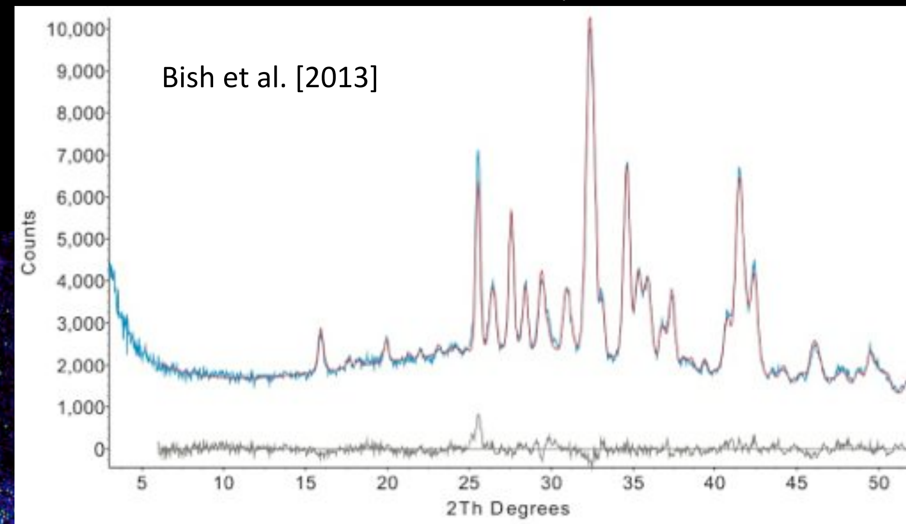
Curiosity's Science Payload Allows Unique Science & ISRU ROI Characterization

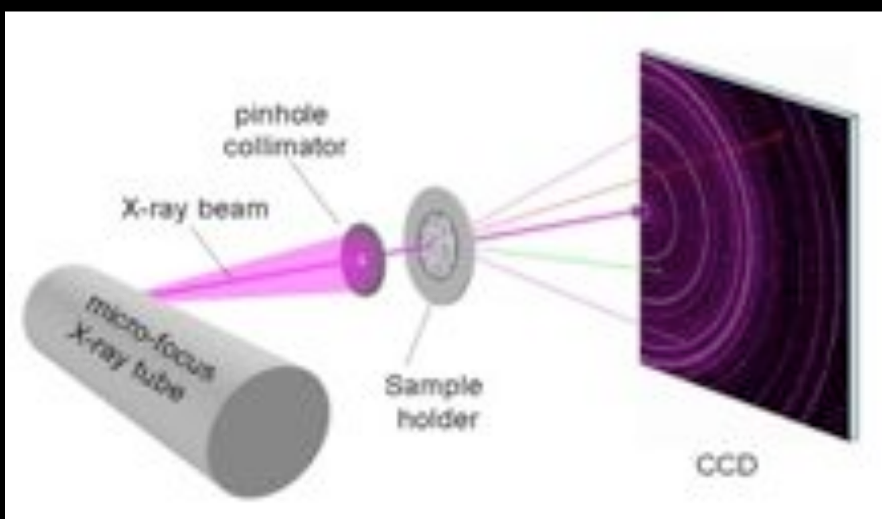


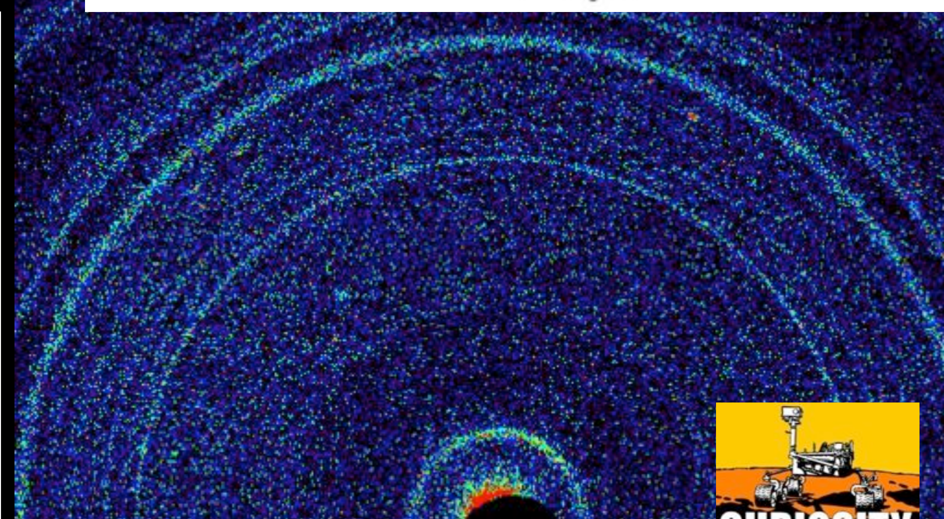
Rocknest sand has a typical Mars basalt composition, but also 1.5-3% bound water. Both a water and food growth medium.

Rocknest sand is composed of unaltered basaltic minerals, typical of rocks and soils on Mars

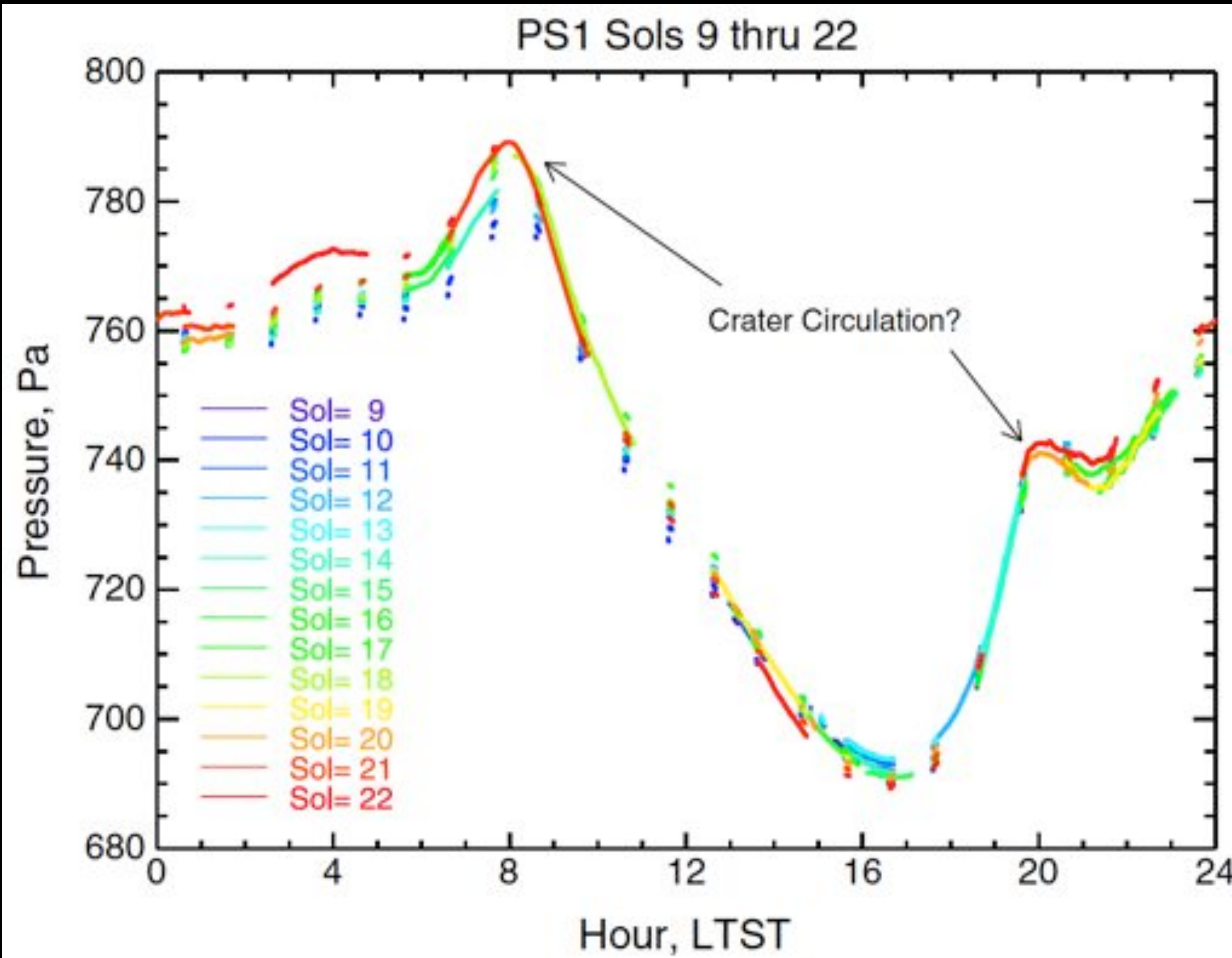
Samples also contained 30-45% non-crystalline material, containing volatiles, sulfur, calcium, and perhaps nanophase ferric oxide.







REMS insitu pressure measurements reveal local, mesoscale, and planetary phenomena



REMS takes hourly measurements with occasional 1-Hz extended sessions

Daytime convective vortices are present, but no dust devils have been observed

Diurnal thermal tides (left) are amplified and modified by the crater topography

The CO_2 pressure cycle at Gale also has components due to elevation and planetary circulations

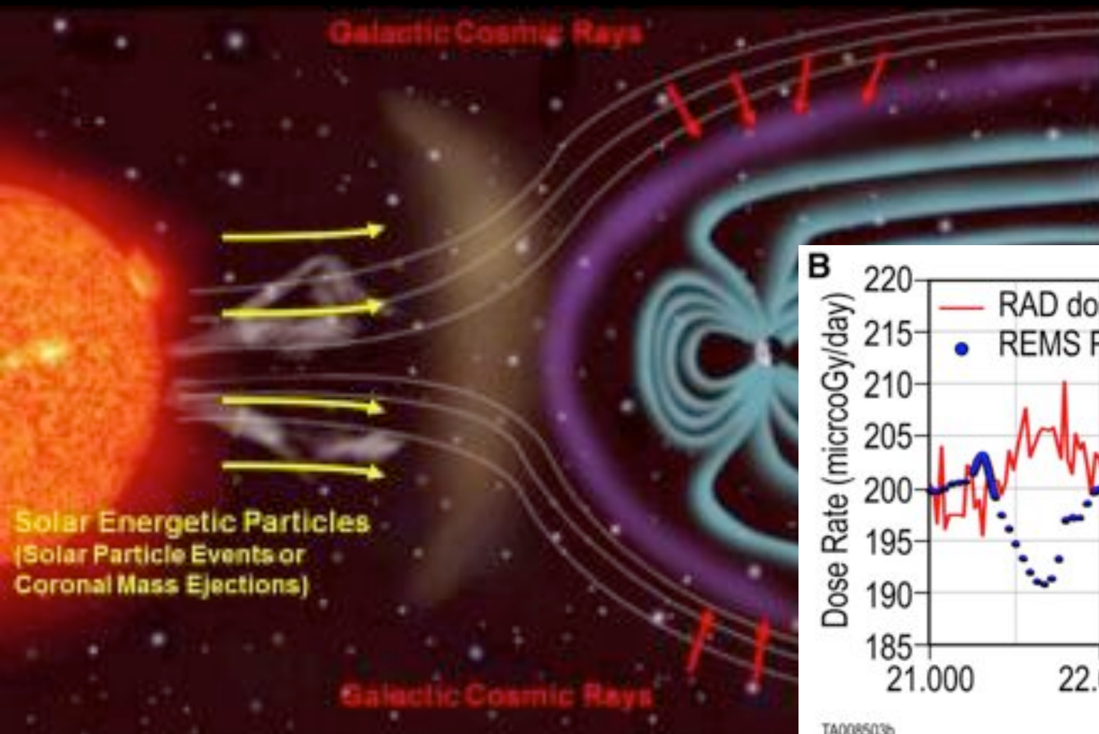
CURIOSITY

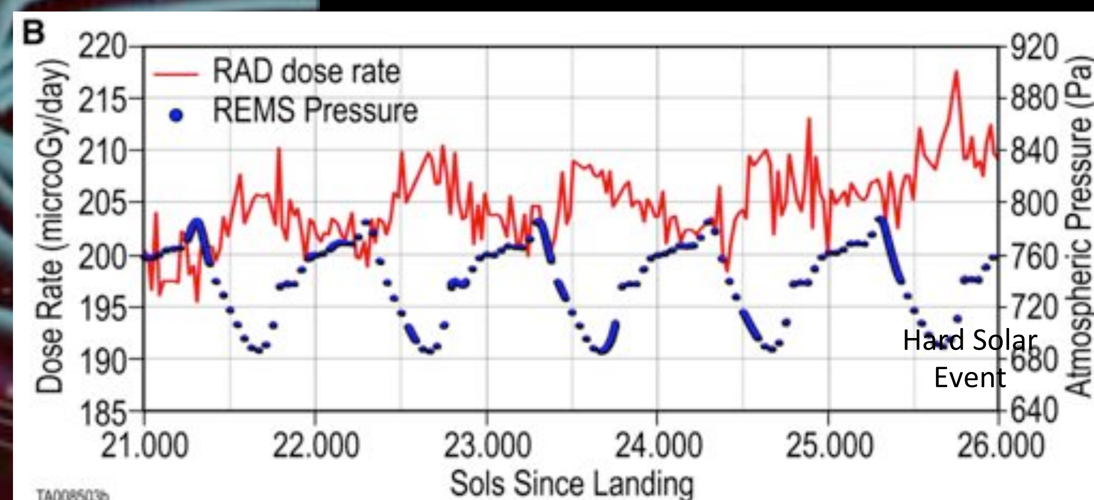
The RAD instrument measured the radiation flux from both galactic cosmic rays and solar energetic particles: *measured radiation hazard at the surface*

The surface dose rate is about half that measured in cruise

A crewed mission would receive ~1 Sievert of exposure in a trip to Mars with 500 sols on the surface

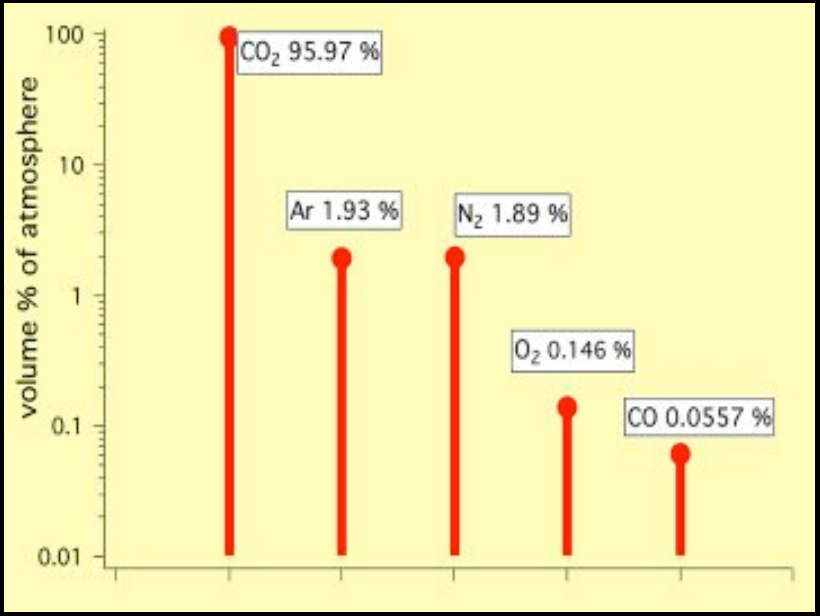
[Hassler et al., 2014]





Curiosity's Radiation Assessment Detector measures high-energy radiation

Atmospheric Gas Abundances Measured by SAM: *Methane detection on surface*



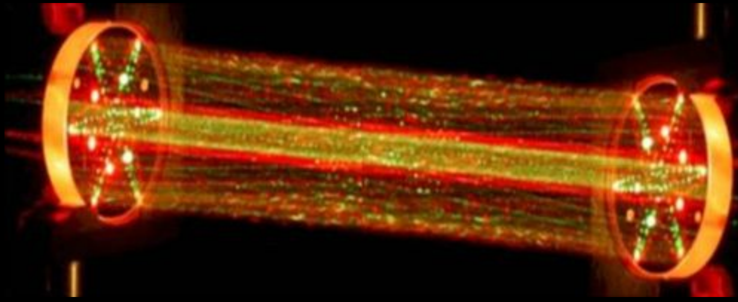
SAM also found that Mars' atmosphere is enriched in the heavy versions of isotopes, indicating massive atmospheric loss to space

$\delta^{13}C = 46 \pm 4$ per mil

$\delta D = 4950 \pm 1080$ per mil

$^{40}Ar/^{36}Ar = 1900 \pm 300$

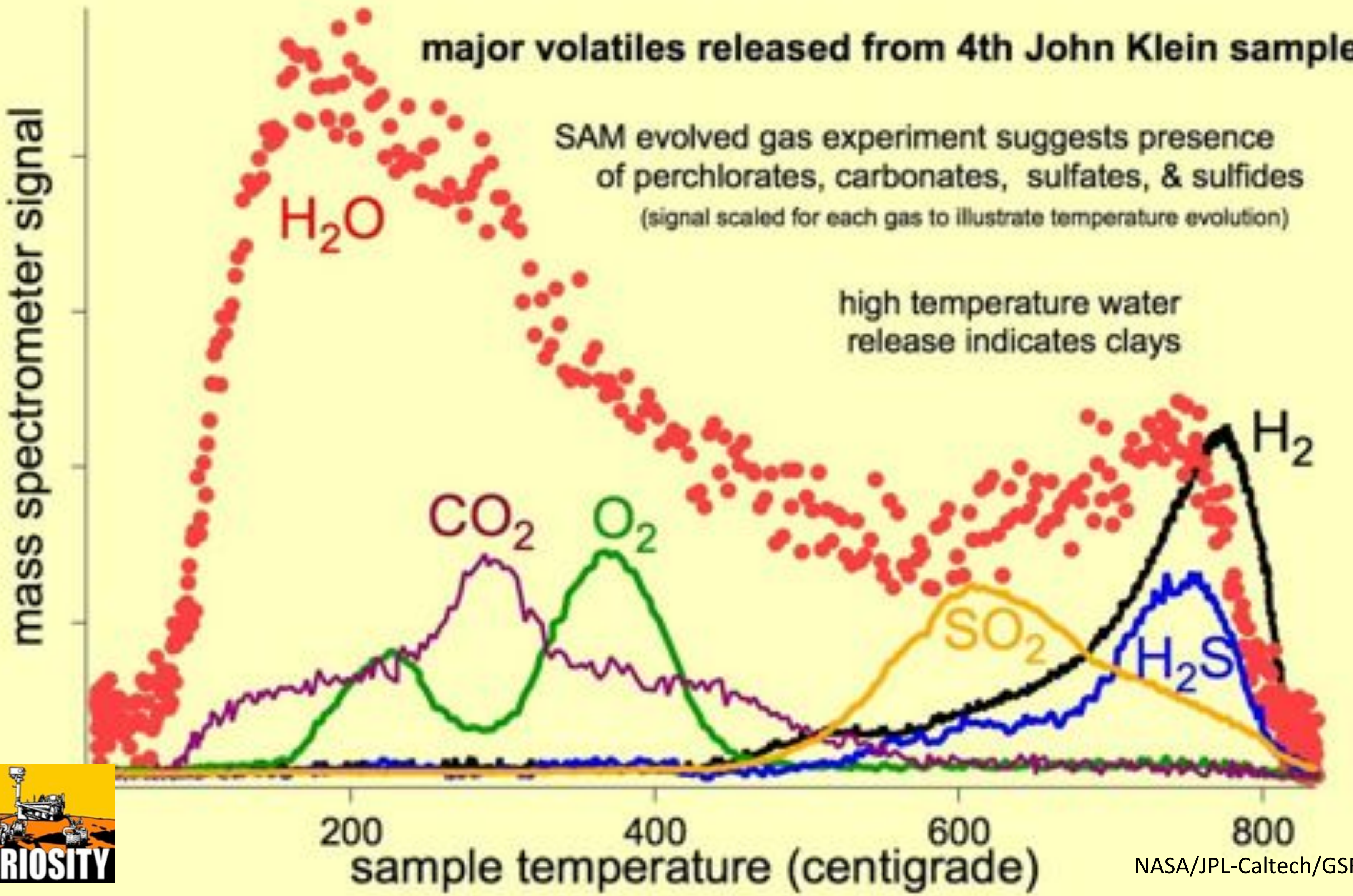
Methane HAS been definitively detected
Upper limit = ~7 ppb



SAM found that argon, rather than nitrogen is the second most abundant gas

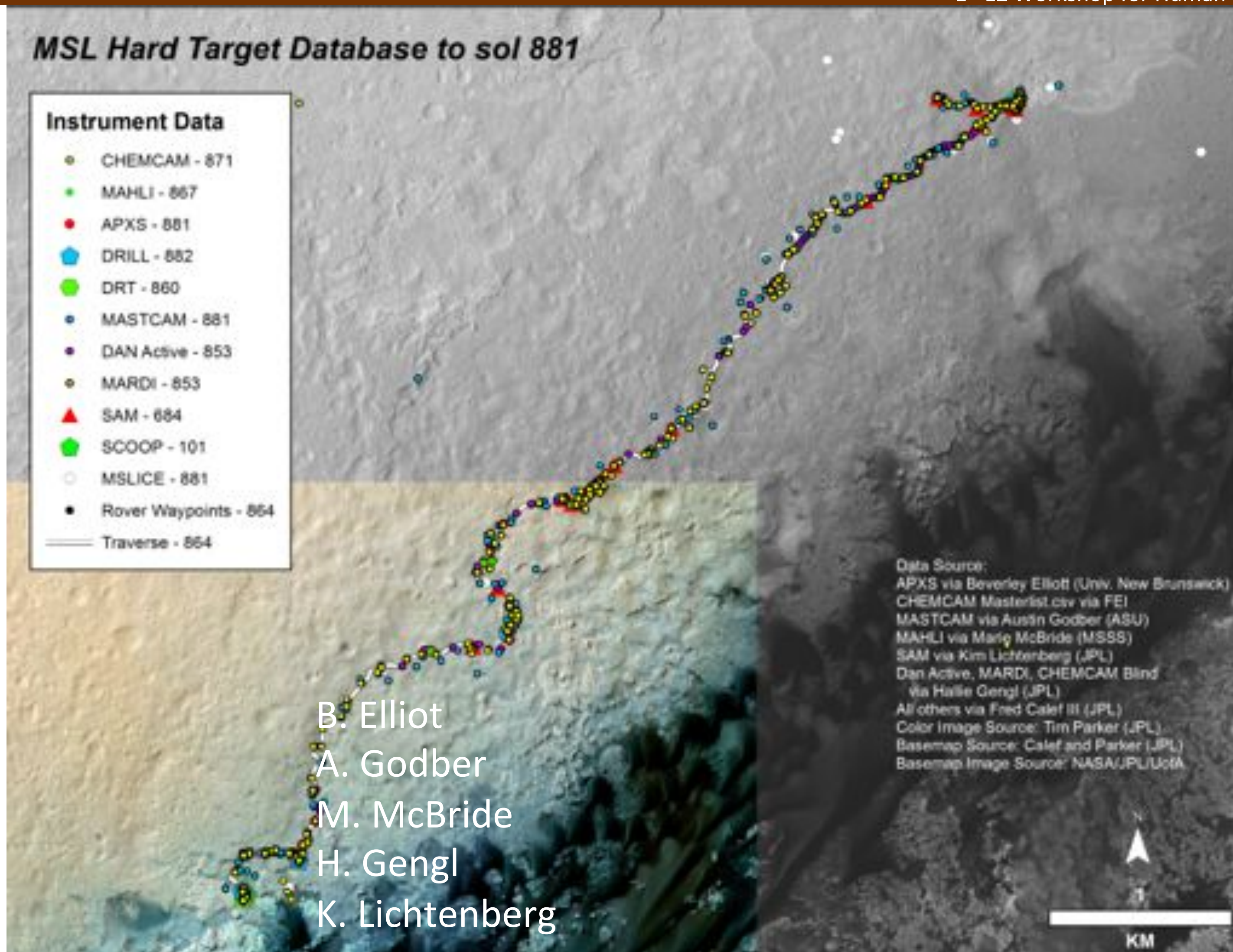
CURIOSITY

Major gases released from John Klein sample and analyzed by SAM: determined Yellowknife Bay was a Habitable Environment when Gale Crater had a Lake



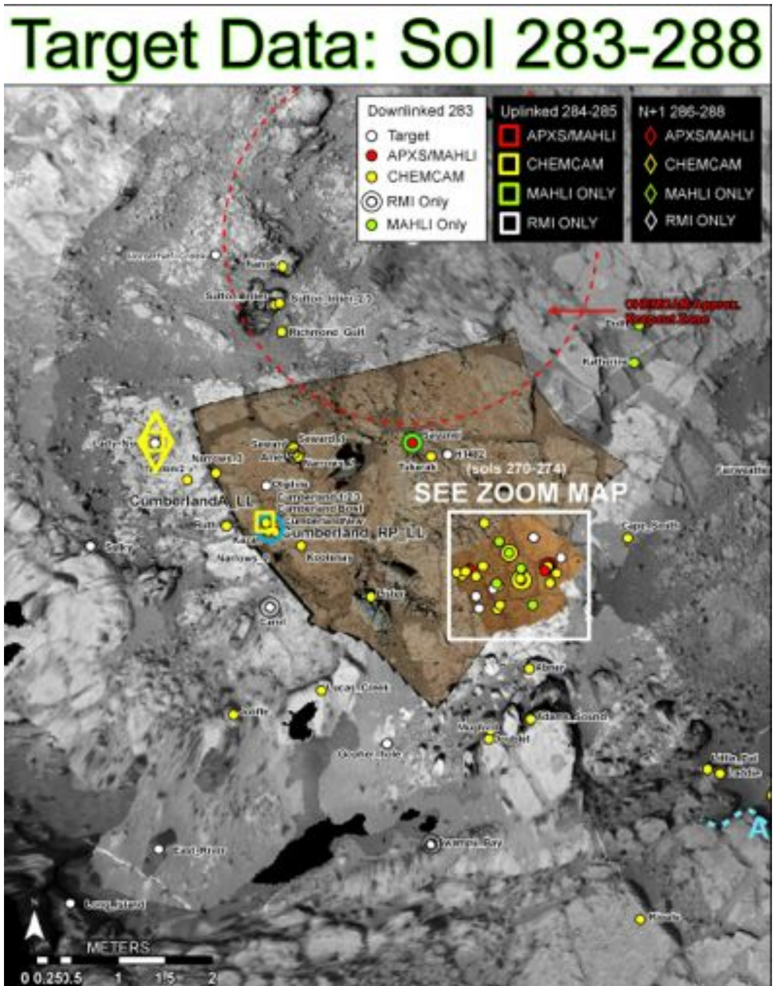
NASA/JPL-Caltech/GSFC

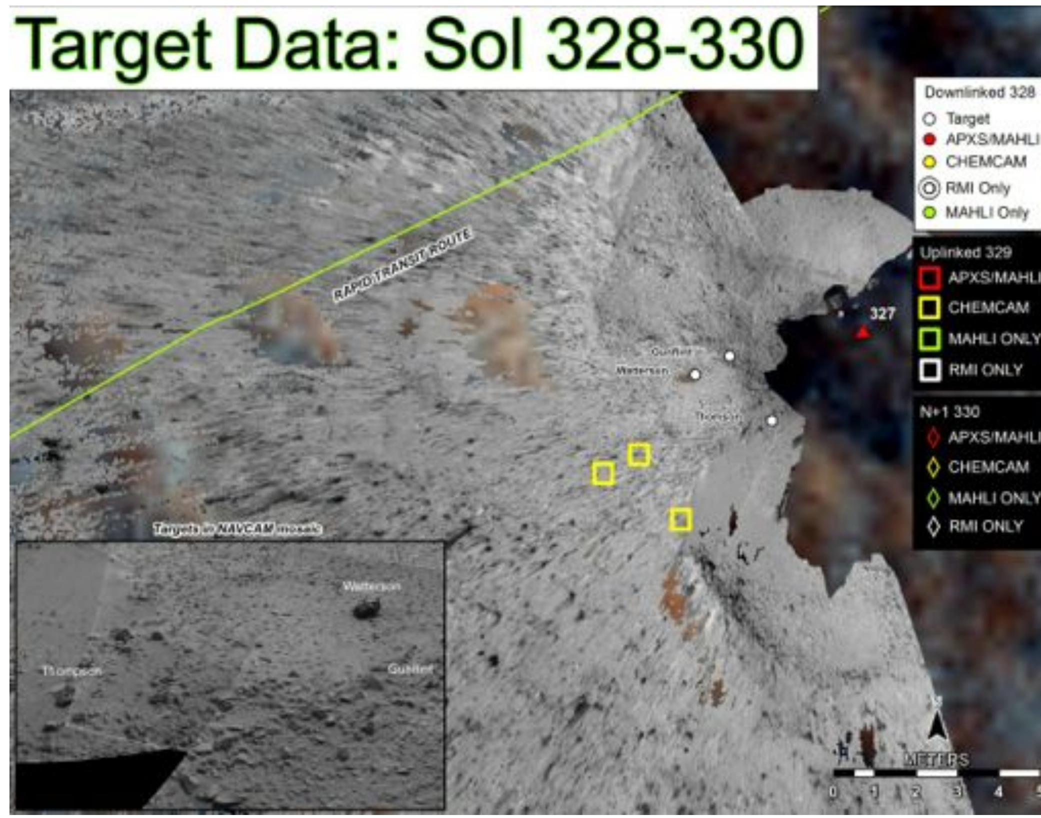
Tracking Science Observations: thousands of potential sample locations known to cm scale



B. Elliot
A. Godber
M. McBride
H. Gengl
K. Lichtenberg

Example Target Map from MSL Operations: known locations for future science opportunities maximize science return during field excursions

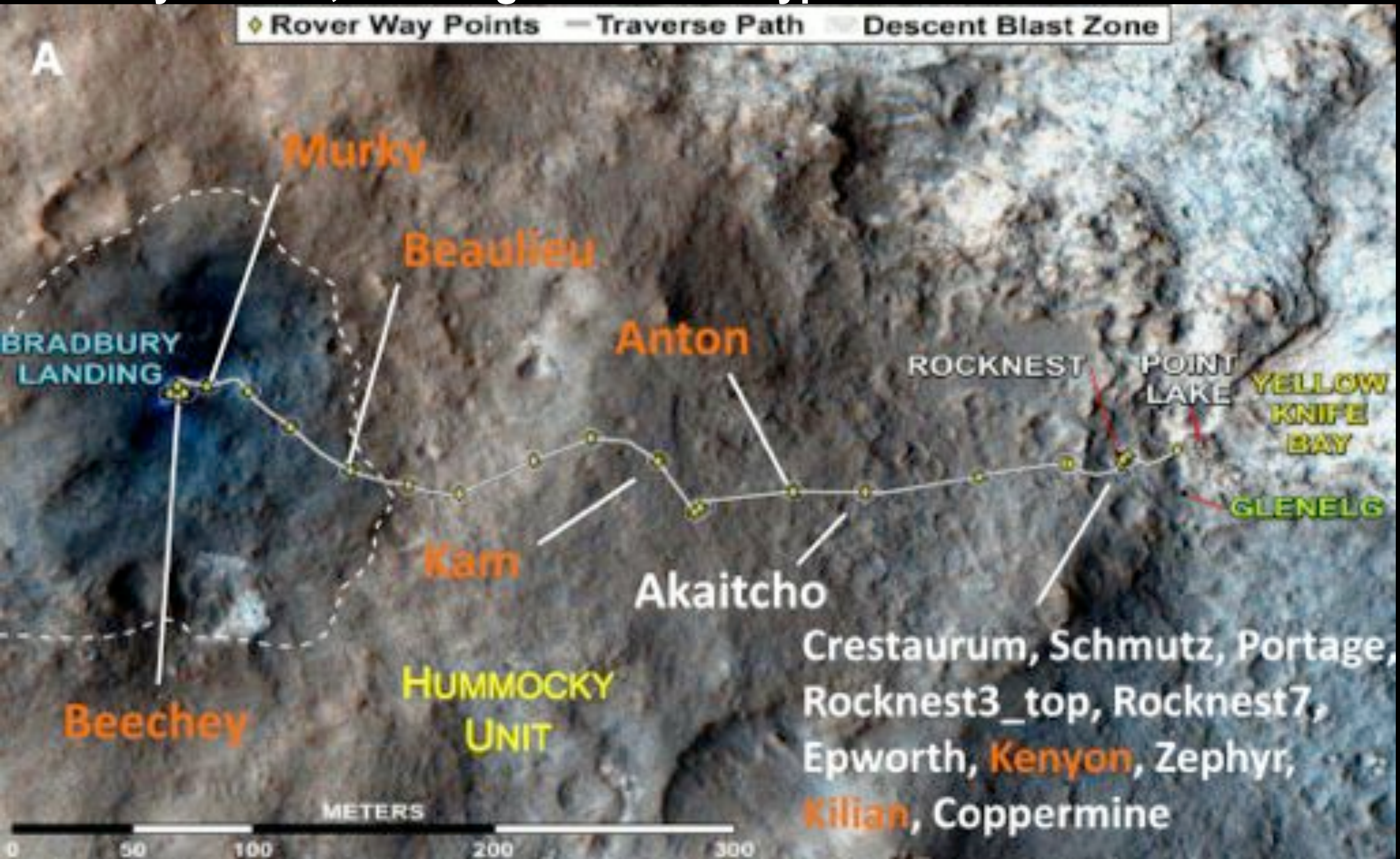




Felsic vs. Mafic ISRU Source Areas

ChemCam identified two principal soil types along the traverse to Yellowknife Bay: a fine-grained, mafic type similar to other soils, and a locally derived, coarse-grained felsic type.

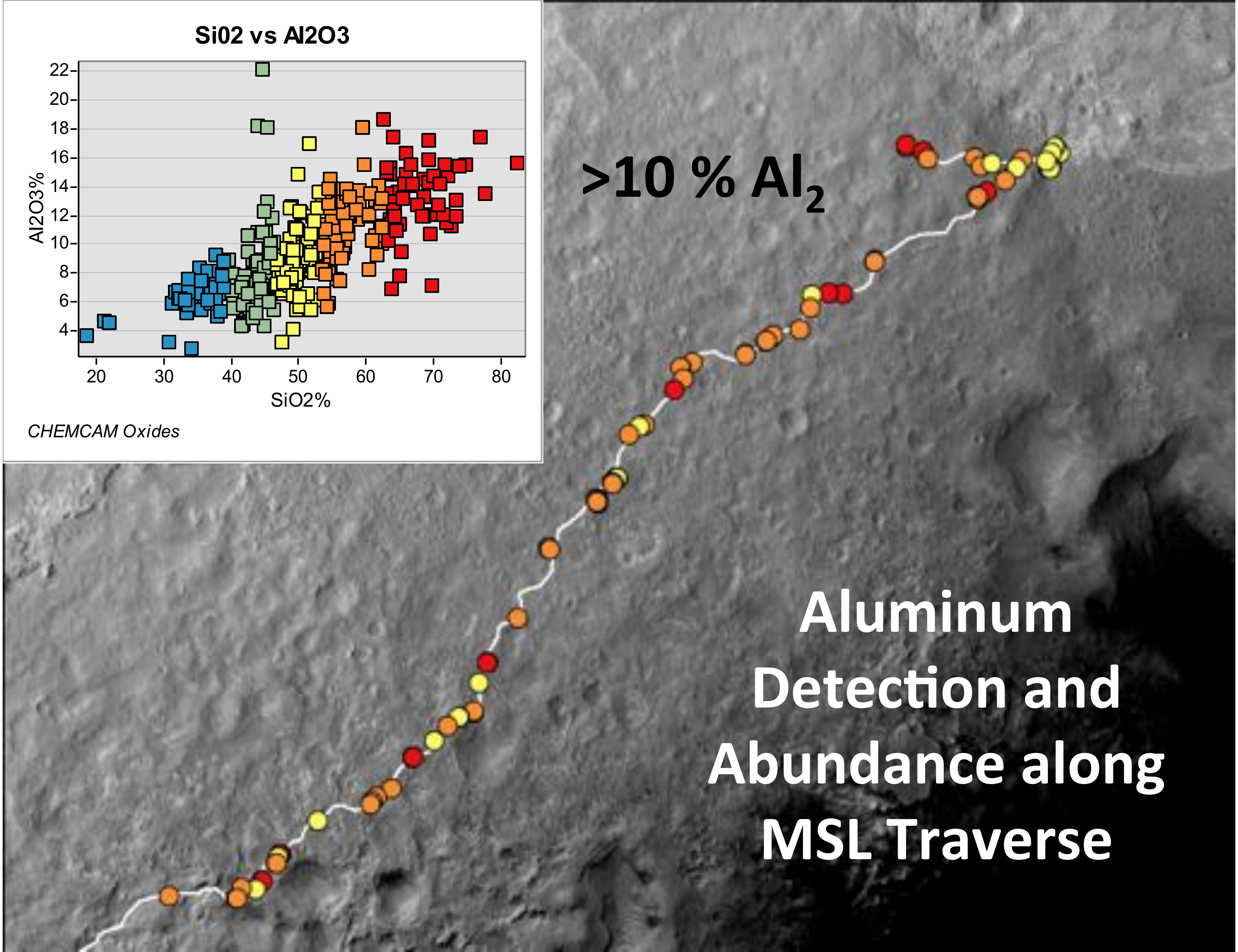
Mafic soil component has hydration signature, corresponding to the X-ray amorphous component sampled by CheMin and SAM.

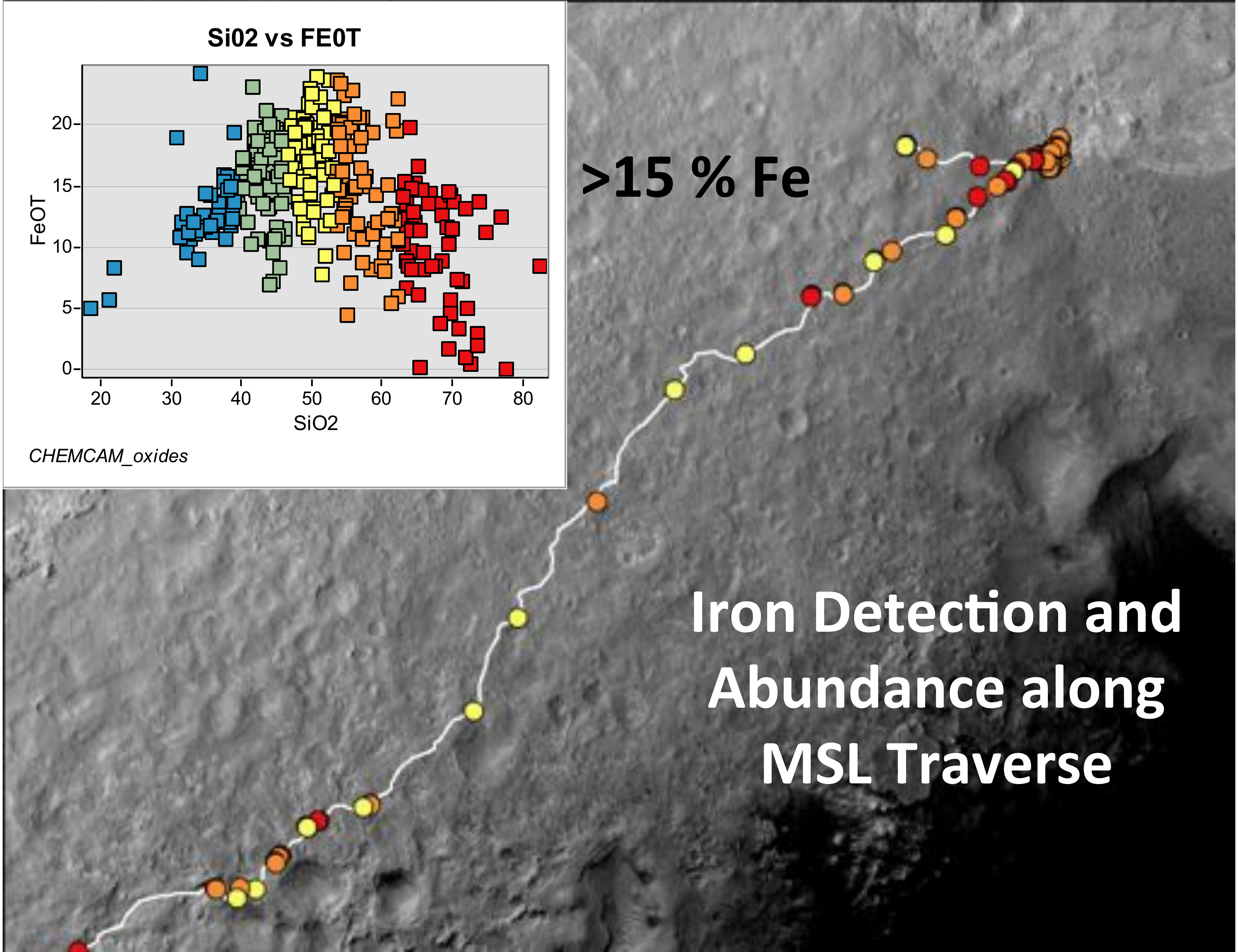


Meslin et al. [2013]

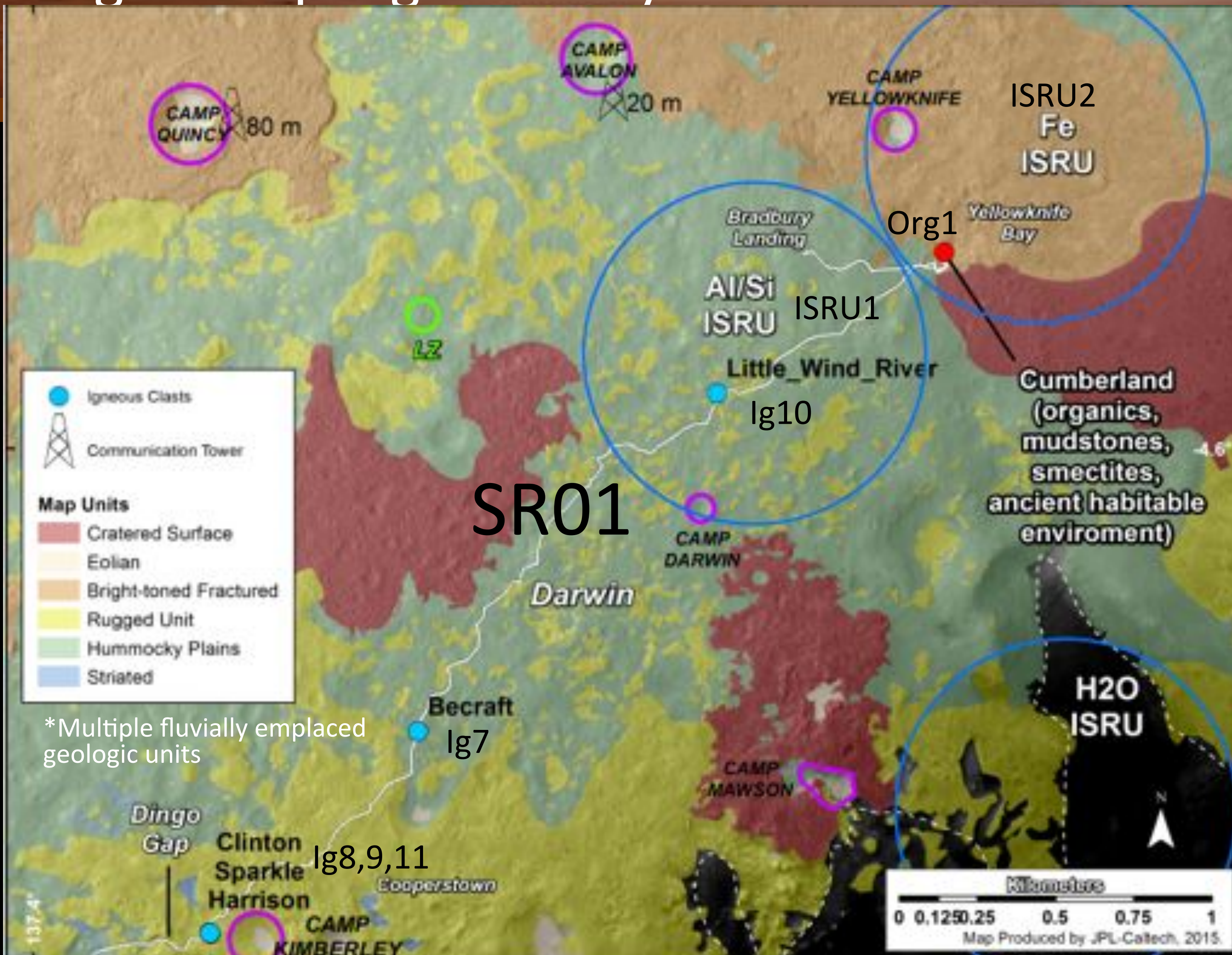
Mafic

Felsic


Si02 vs Al2O3
Al2O3%
22
20
18
16
14
12
10
8
6
4
20
30
40
50
60
70
80
SiO2%
CHEMCAM Oxides
>10 % Al$_2$
Aluminum Detection and Abundance along MSL Traverse

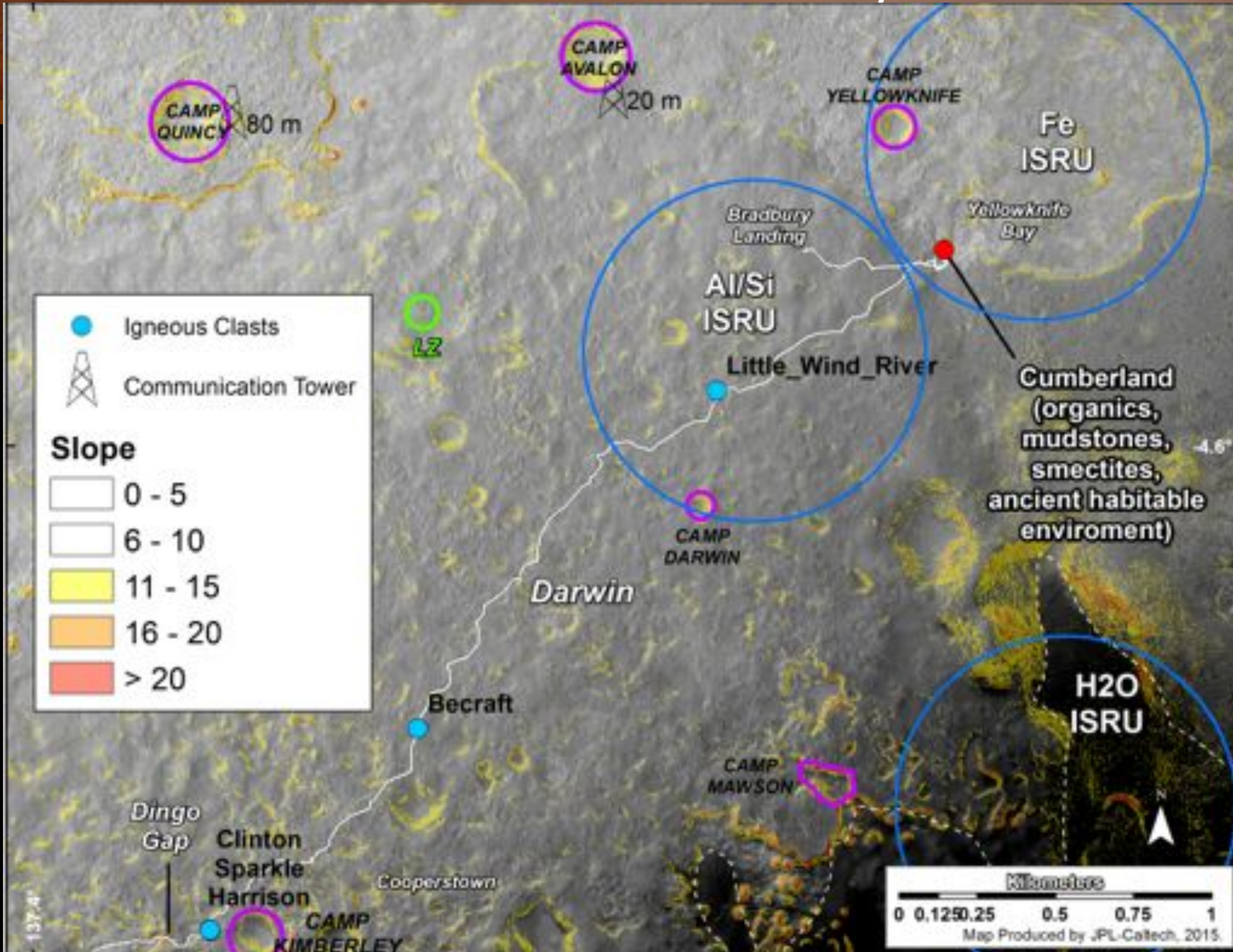

Si02 vs FE0T
FeOT
SiO2
0
5
10
15
20
20
30
40
50
60
70
80
CHEMCAM_oxides
>15 % Fe
Iron Detection and Abundance along MSL Traverse

1st Mission Exploration Zone: Geologic Sampling Diversity within 1-2 Kilometers



ons to Mars

1st Mission Exploration Zone: Potential Habitation Sites and nearby ISRU Zones



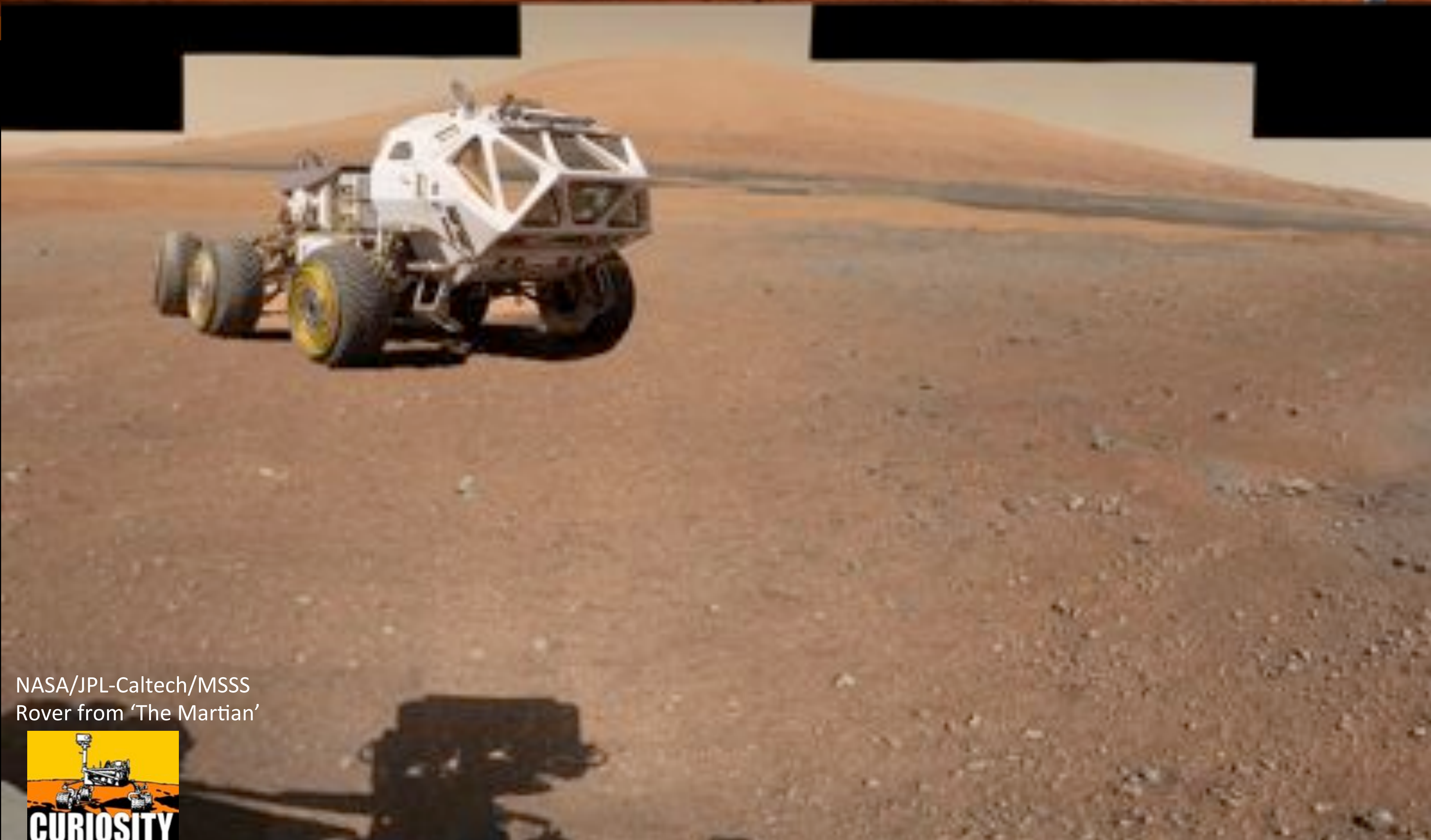
ISRU Resource Numbers: Water

- Water
  - Based on Leshin et al. (2013), Rocknest sands contained up to 3 wt% H_2O via SAM, Bagnold Dune field contains 10^4-10^6 MT **adsorbed** water.
  - Easy to process. Potentially ‘reuseable’.

ISRU Resource Numbers: Metals

- Aluminum and Silicon
  - ISRU01 rocks on average have ~12 wt% Al and ~55-60 wt% Si. ISRU02 rocks, ~18 wt% Fe.
  - Assuming rock density ~2.5 gm/cc:
    - 300 kg/m^3 Al (ISRU01)
    - 1375-1500 kg/m^3 Si (ISRU01)
    - 450 kg/m^3 Fe (ISRU02)

What the surface actually looks like at the (human) landing site…



NASA/JPL-Caltech/MSSS
Rover from 'The Martian'

Building material and ISRU Al/Si Resource Rounded pebbles and sand in the conglomerate "Link"

Science Target: Large feldspar-rich crystals (phenocrysts) in an igneous clast (Harrison): good for geologic dating

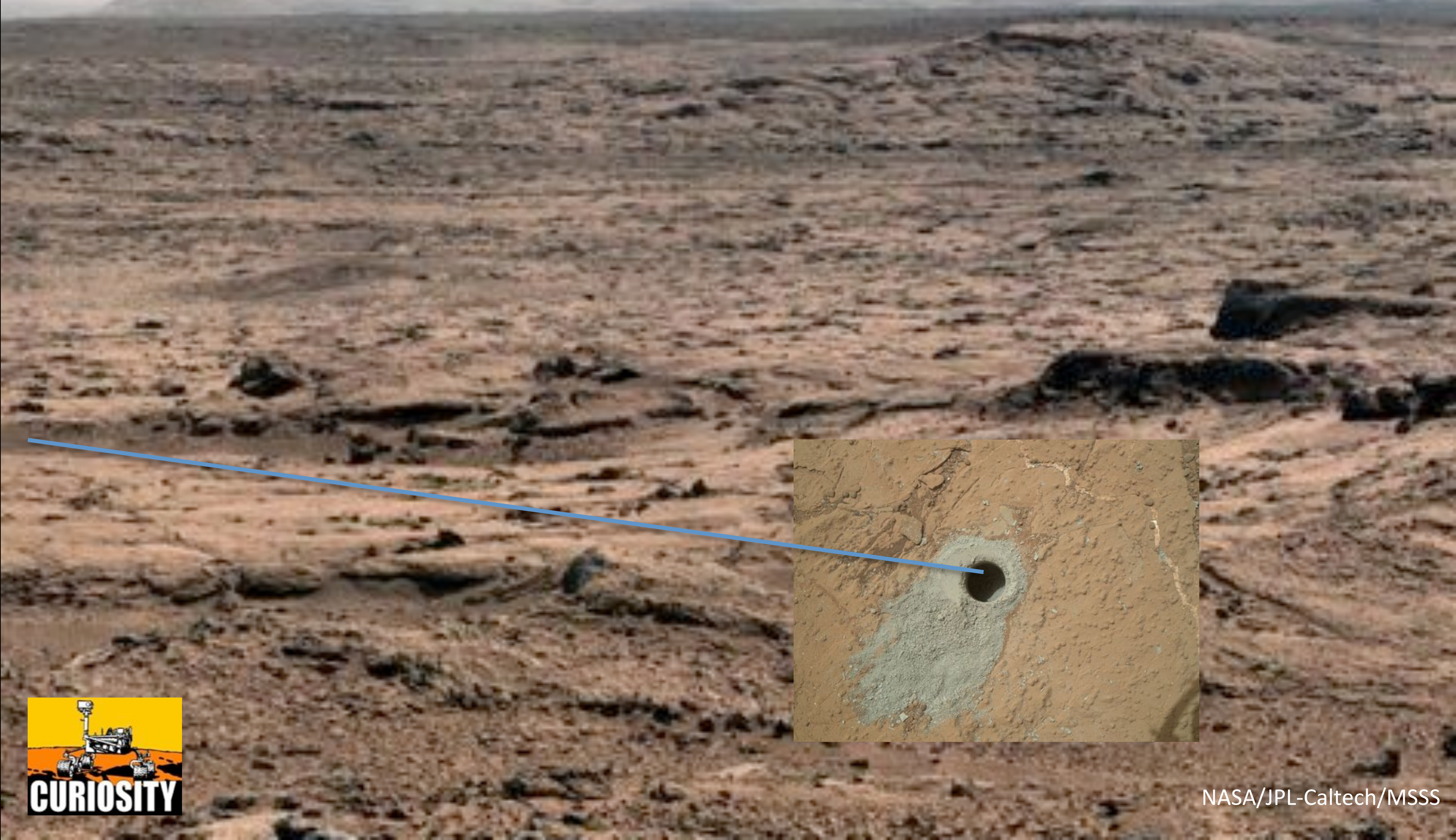
SRIg09 Harrison (lat, lon, elev)
-4.62617745, 137.40955945, -4489.114 m

S

CURIOSITY

Science ROI: Yellowknife Bay for Organics and Lake sediments (Sheepbed Mudstones)

Cumberland Drill Site with martian organic detection:
lon., lat, elev: 137.44909593, -4.58951574, -4520.029 m



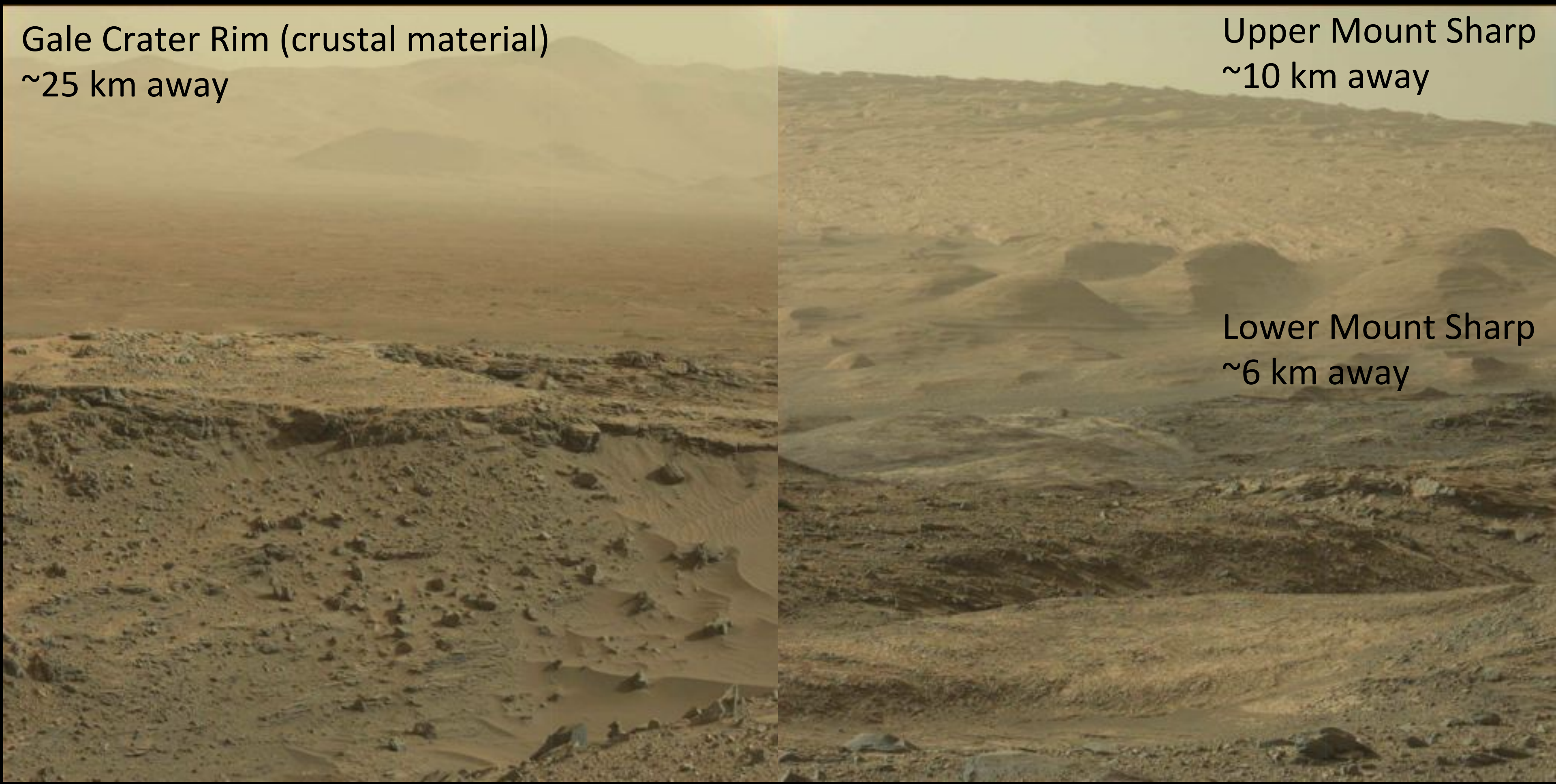
NASA/JPL-Caltech/MSSS

A Known Ancient Habitable Environment at Yellowknife Bay

- The regional geology and fine-grained rock suggest that the John Klein site was at the end of an ancient river system or within an intermittently wet lake bed
- The mineralogy indicates sustained interaction with liquid water that was not too acidic or alkaline, and low salinity. Furthermore, conditions were not strongly oxidizing.
- Key chemical ingredients for life are present, such as carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur
- The presence of minerals in various states of oxidation would provide a source of energy for primitive organisms

NASA/JPL-Caltech/MSSS

How Close are Distal Science ROIs from Landing Site: Almost all within Walkback Distance



Reference Mission Goals

- In regards to Mars design reference architecture.
  - Gale crater easily meets all the science and engineering goals given its selection for the MSL rover mission.
  - "Short-stay" with 30 days on the surface (500-650 days total) and "long-stay" with 500+ days on Mars (~900 days total) are supported as we have the localization of science targets down to the centimeter in a concentrated area (<10 km radius circle). *Supports JPL 'minimal architecture (Price, Baker, and Naderi, *New Space*, 2015).
  - Gale crater offers crustal material within ~20-25 km at the rim, Aeolis Mons (Mt. Sharp) clay to sulfate transition within ~15 km, primary alluvial fan material <5 km and fluvially derived conglomerates and clays, some lacustrine, upon landing in many areas of the current MSL ellipse. *Well within 'walk-back' distance for astronauts.
  - Many known scientific outcrops at Gale crater are <4 km radius from field station/ habitat, if the human habitat where placed within the current MSL landing ellipse area.
  - Outcrops would be close, safe, and pre-characterized sufficiently by Curiosity to allow short or long-stay missions.
- **Conclusion:** Gale crater provides excellent EDL, ISRU, and science opportunities for a human-rated mission.

RUBRICS

Science ROI(s) Rubric

Science Site Criteria				Site Factors	SRIg01-06	SRIg07-11	SRIC01-02	SROrg1	SRF01-04	SRC01-06	SR01		EZ SUM
Science Site Criteria	Astrobio	Threshold	AND/OR	Potential for past habitability			○	●	●				5,1
				Potential for present habitability/refugia							○		0,1
		Qualifying		Potential for organic matter, w/ surface exposure			○	●	○	○			1,11
	Atmospheric Science	Threshold		Noachian/Hesperian rocks w/ trapped atmospheric gases				●	●		●		6,0
		Qualifying		Meteorological diversity in space and time							●		1,0
				High likelihood of surface-atmosphere exchange							●		1,0
				Amazonian subsurface or high-latitude ice or sediment									
				High likelihood of active trace gas sources							○		0,1
	Geoscience	Threshold		Range of martian geologic time; datable surfaces	●	●			●	●			21, 0
				Evidence of aqueous processes			●	●	●	●			13, 0
				Potential for interpreting relative ages	●	●	●	●	●	●			20, 0
		Qualifying		Igneous Rocks tied to 1+ provinces or different times	●	●							11, 0
				Near-surface ice, glacial or permafrost									
				Noachian or pre-Noachian bedrock units	●	●	?						11, 0
				Outcrops with remnant magnetization	○	○							0, 11
				Primary, secondary, and basin-forming impact deposits							●		1, 0
				Structural features with regional or global context	●	●		●			●		13, 0
				Diversity of aeolian sediments and/or landforms							●		1, 0

Key	
●	Yes
○	Partial Support or Debated
	No
?	Indeterminate

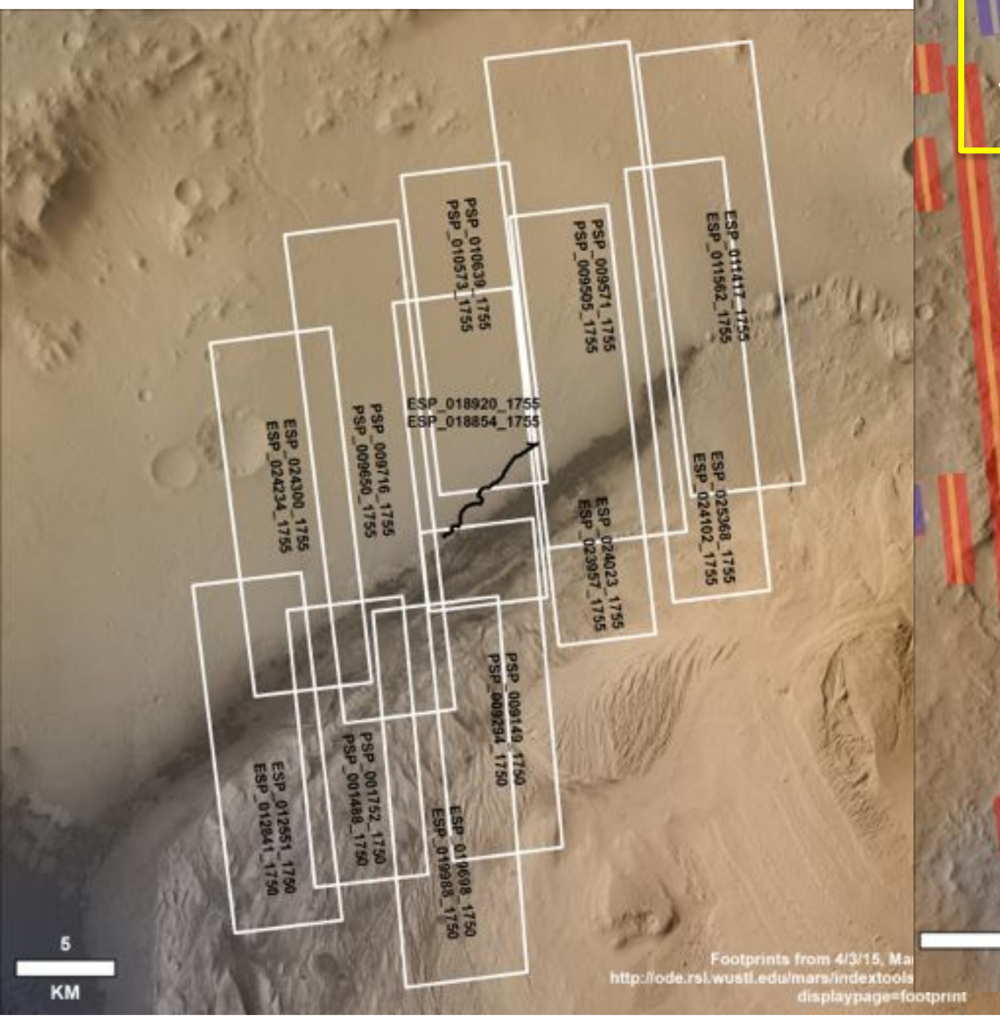
Resource ROI(s) Rubric

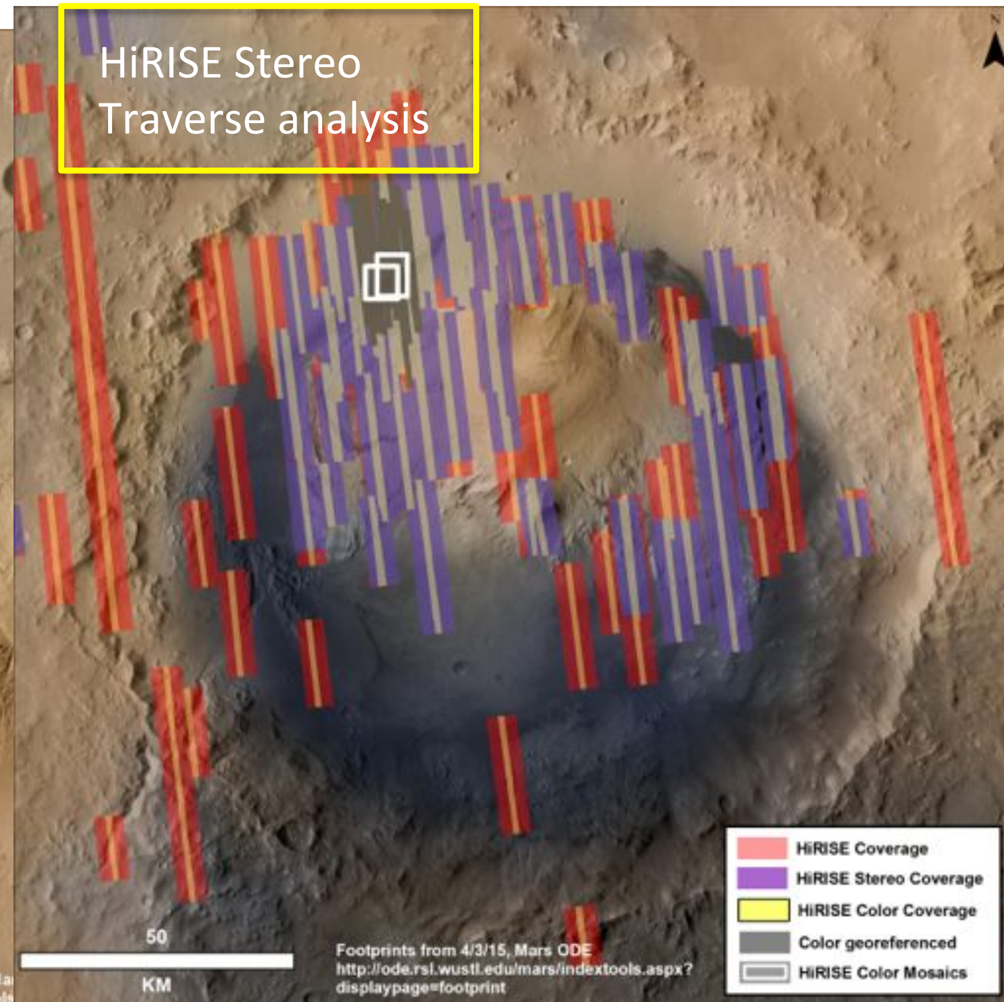
Site Factors				RW01-04	RISUR1	LZ01	ISRU2					EZ SUM
ISRU and Civil Engineering Criteria	Engineering		Meets First Order Criteria (Latitude, Elevation, Thermal Inertia)			●						1
	Water Resource	Threshold	AND/OR: Potential for ice or ice/regolith mix									
			AND/OR: Potential for hydrated minerals	●								4
			Quantity for substantial production	●								4
			Potential to be minable by highly automated systems	●								4
			Located less than 3 km from processing equipment site	●								1
			Located no more than 3 meters below the surface	●								4
			Accessible by automated systems	●								4
		Qualifying	Potential for multiple sources of ice, ice/regolith mix **and** hydrated minerals									
			Distance to resource location can be >5 km	●								3
			Route to resource location must be (plausibly) traversable	●								3
	Civil Engineering	Threshold	~50 sq km region of flat and stable terrain with sparse rock distribution			●						1
			1–10 km length scale: <10°			●						1
			Located within 5 km of landing site location			●						1
		Qualifying	Located in the northern hemisphere			○						0, 1
			Evidence of abundant cobble sized or smaller rocks and bulk, loose regolith			●						1
			Utilitarian terrain features			●						1
	Food Production	Qualifying	Low latitude			●						1
			No local terrain feature(s) that could shadow light collection facilities			●						1
			Access to water			●						1
			Access to dark, minimally altered basaltic sands			●						1
	Metal/Silicon Resource	Threshold	Potential for metal/silicon		●		●					2
			Potential to be minable by highly automated systems		●		●					2
			Located less than 3 km from processing equipment site		●		●					2
			Located no more than 3 meters below the surface		●		●					2
			Accessible by automated systems									
		Qualifying	Potential for multiple sources of metals/silicon		●		●					2
			Distance to resource location can be >5 km		●		●					2
			Route to resource location must be (plausibly) traversable		●		●					2

Key	
●	Yes
○	Partial Support or Debated
	No
?	Indeterminate

DATA NEEDS

HiRISE Coverage Needed for Long Distance Traverse Analysis





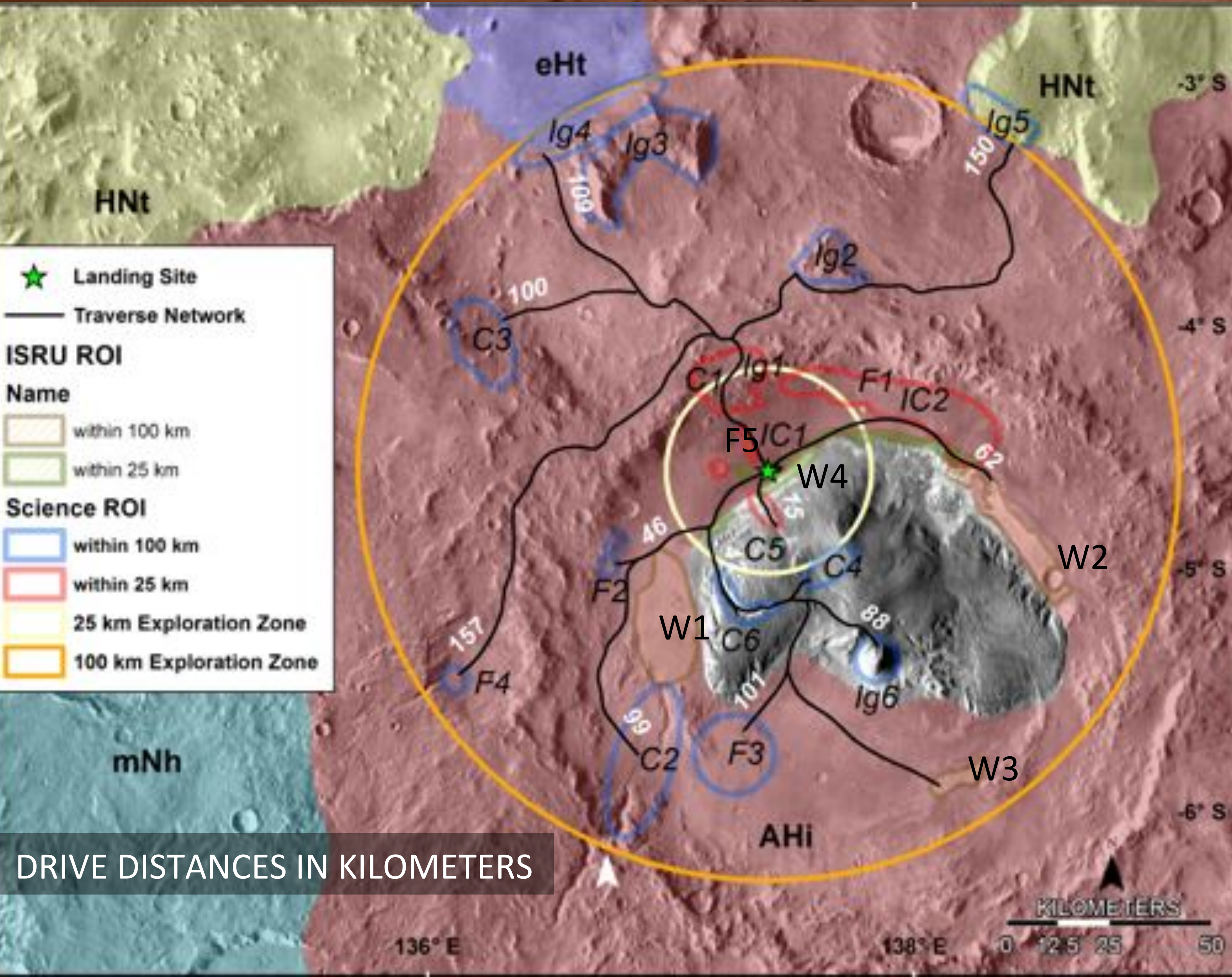
Highest Priority EZ Data Needs

- HiRISE Stereo of traverse exiting Gale crater to the north and northwest via Peace Vallis.
- CTX and/or HiRISE Stereo along traverse route outside Gale crater to potential volcanic unit.

[in order of priority: addressing threshold first, then qualifying]

SCIENCE ROIs

Gale Crater Exploration Zone



for Human Missions to Mars

LZ Coordinates

Longitude (E)

137.42009295°

Latitude (S)

4.59310427°

Elevation (MOLA)

-4497.77

Easting

8145534.27 m

Northing

-272254.70 m

Science ROI

C = Channel

F = Fan

Ig = Igneous

IC = Inverted Channels

ISRU ROI

W = Water ROI

Science ROI: Known Organics SROrg01

Cumberland drill hole site in Yellowknife Bay in Gale crater. The ONLY confirmed presence of insitu martian organics. Image NASA/JPL-Caltech/MSSS/

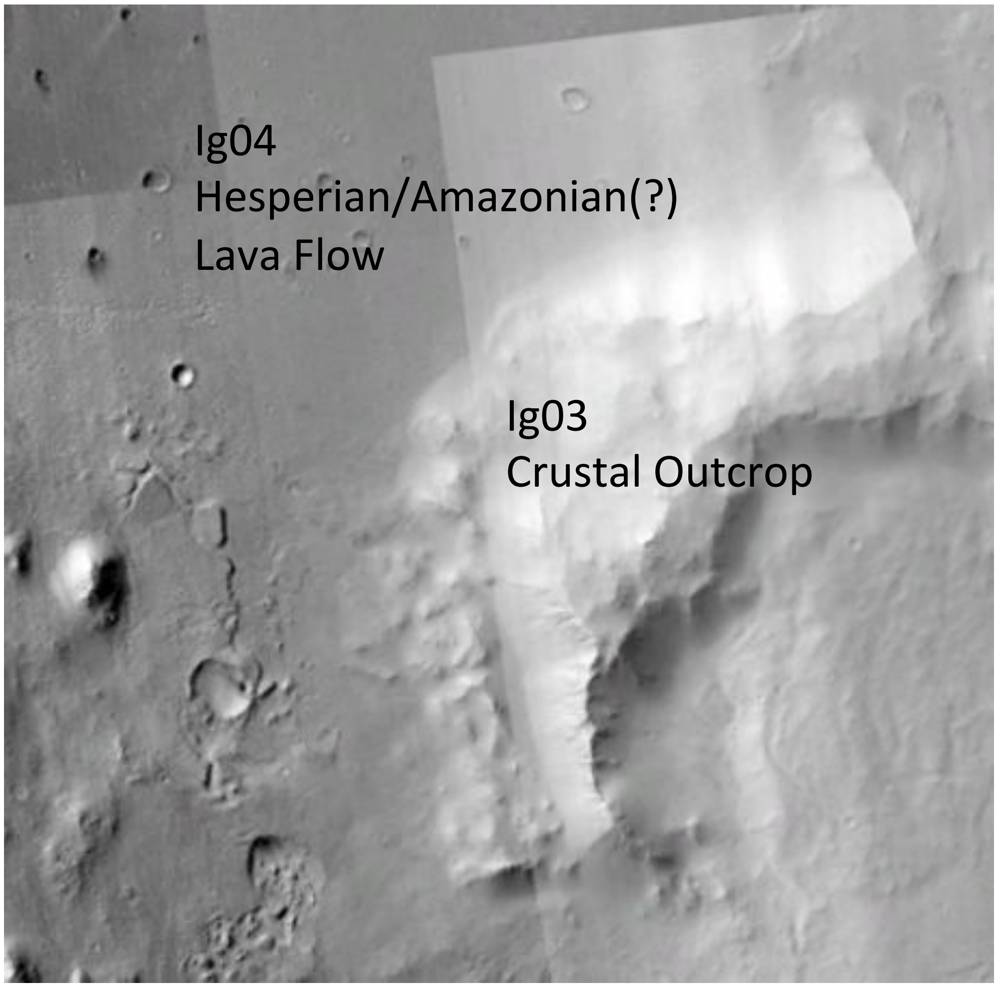
ROI, Latitude, Longitude

- SROrg01

137.44909593, -4.58951574, -4520.029 m

- Martian Organics: CONFIRMED
- Ancient Habitable Environment: CONFIRMED
- Aqueous Processes: Lake environment
- Goal: access organics below ~ 4 m for best preservation

Science ROI: Dateable Rocks SRIg01-06



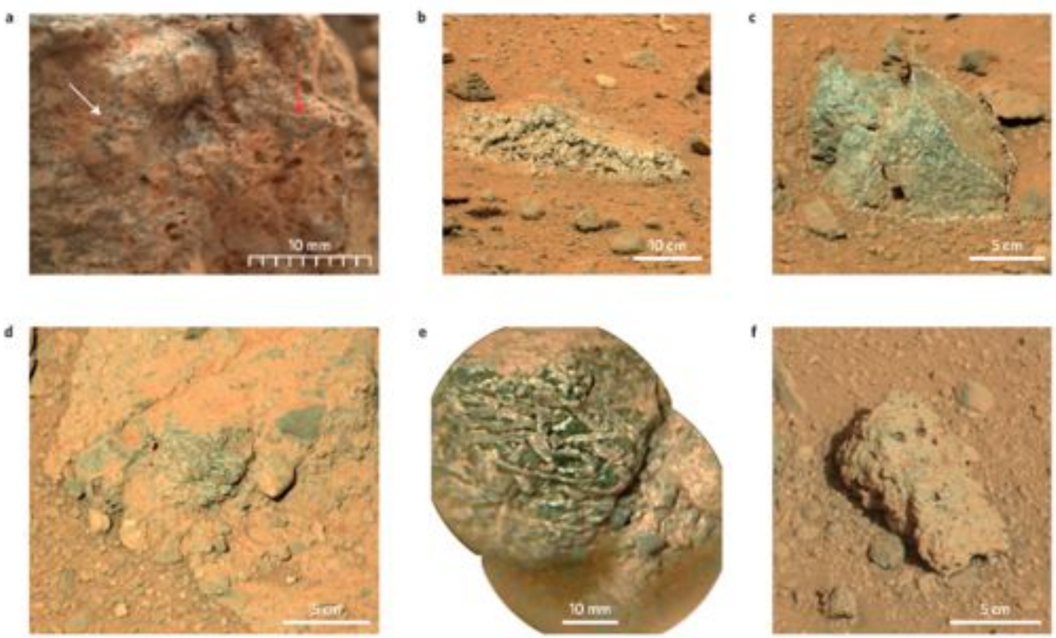
Dissected Noachian terrain (Ig03) and Amazonian (?) lava flow (Ig04)

ROI, Latitude, Longitude

- SRIg01
-4.253, 137.2109, -3514 m
- SRIg02
-4.62615916, 137.40954931, -4489.232 m
- SRIg03
-3.2417, 136.8176, -643 m
- SRIg04
-3.3081, 136.4805, -2634 m
- SRIg05
-3.1855, 138.2886, -2253 m
- SRIg06
-5.3715, 137.8544, 731 m

- Dateable Crustal Rocks
- Goal: obtain inplace igneous rocks from Noachian crust and Amazonian lava flow.

Science ROI: Dateable Igneous Rocks SRIg07-11



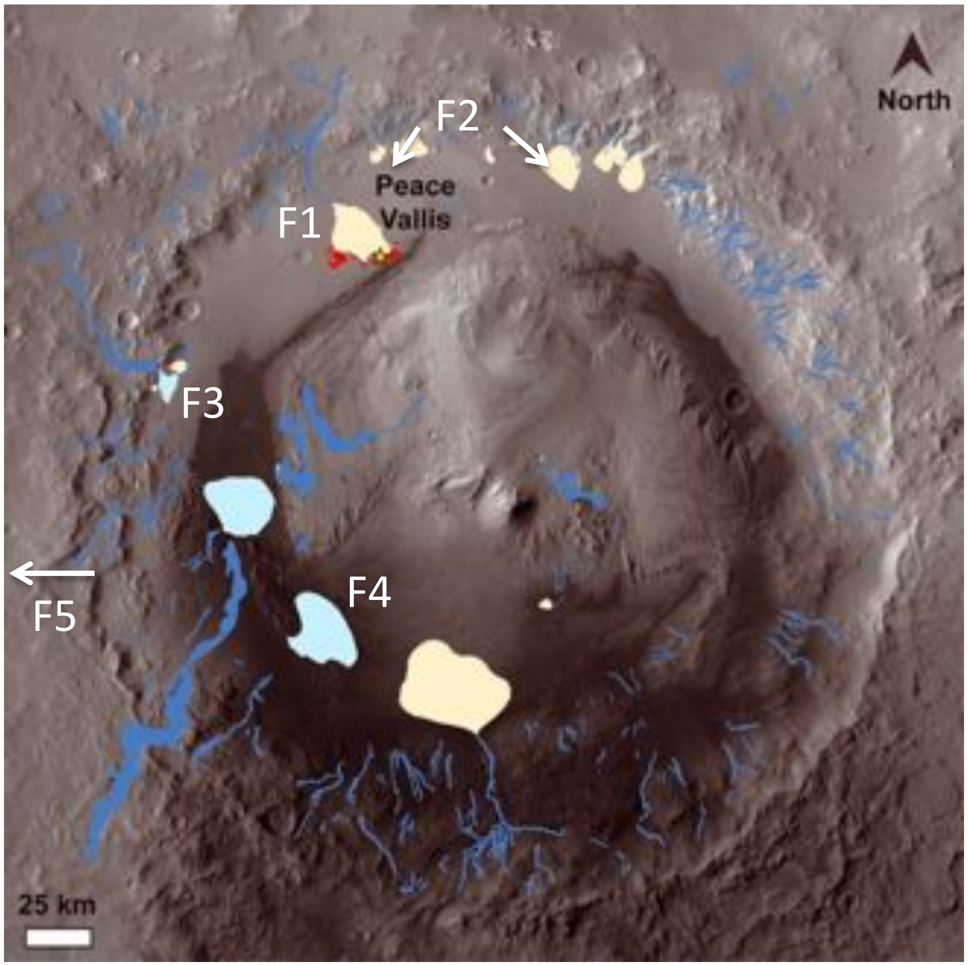
Examples of various igneous rocks found along Curiosity's traverse, from Sautter et al., 2015. These rocks are expected to be from a local source within the crater, possibly from the rim.

ROI, Latitude, Longitude

- SRIg07 Becraft (lat,lon)
-4.6152702, 137.42078452, -4498.119 m
- SRIg08 Clinton (lat,lon)
-4.62615916, 137.40954931, -4489.232 m
- SRIg09 Harrison (lat,lon)
-4.62617745, 137.40955945, -4489.114 m
- SRIg10 Little Wind River (lat,lon)
-4.59700021, 137.4369205, -4500.566 m
- SRIg11 Sparkle (lat,lon)
-4.62620416, 137.40957441, -4489.030 m

- Dateable Igneous (Crustal ?) Rocks
- All located close to LZ
- Goal: obtain Noachian aged samples likely from the crater rim.

Science ROI: Alluvial Fans and Potential Deltas SRF01-05



Alluvial fans and potential deltas from Palucis et al., 2013

ROI, Latitude, Longitude

- SRF01 Peace Vallis Alluvial Fan
-4.4549, 137.3476, -4464 m
- SRF02 Alluvial fans NE of Peace Vallis
-4.2852, 137.7909, -3995m
- SRF03 small delta (?) on western rim
-5.0038, 136.7512, -3917 m
- SRF04 ‘pancake delta’ N of Farrah Vallis
-5.7801, 137.2926, -3268 m
- SRF05 fan/delta just W of crater rim
-5.4686, 136.1128, -1474 m

- Aqueous Processes
- Potential Habitable Environments
- Potential Organic Preservation
- Investigate the diverse water level history in Gale/region

Science ROI: Inverted Channels SRIC01-02

Peace Vallis inverted Channel
NASA/JPL-Caltech/UofA

ROI, Latitude, Longitude

- SRIC01

-4.4549, 137.3476, -4464 m

- SRIC02

-4.2852, 137.7909, -3995m

- Aqueous Processes

Science ROI: Channels SRC01-06

Channel cutting western part of lower mound.
NASA/JPL-Caltech/UofA

ROI, Latitude, Longitude

- SRC01 Peace Vallis

-4.253, 137.2109, -3514 m

- SRC02 Farrah Vallis

136.8125, -5.9589, -2302 m

- SRC03 unnamed channel NW of rim

-4.0385, 136.2456, -2159 m

- SRC04 exhumed channel under upper mound

-5.1011, 137.5155, -2012 m

- SRC05 Lower Mt. Sharp

-4.7876, 137.4095, -3650 m

- SRC06 western mound

-5.1417, 137.2671, -2998 m

- Stratigraphic context (late Noachian to Hesperian/Amazonian)
- Aqueous Processes

(in cross-section)

- Dateable Surfaces (?)

[in order of priority: addressing threshold first, then qualifying]

RESOURCE ROIs

H_2O ISRU Resource ISRUW01-04

Barchan dunes of Bagnold dunefield.
NASA/JPL-Caltech/UofA

ROI, Latitude, Longitude

- ISRUW01

-4.253, 137.2109, -3514 m

- ISRUW02

136.8125, -5.9589, -2302 m

- ISRUW03

136.8125, -5.9589, -2302 m

- ISRUW04

136.8125, -5.9589, -2302 m

- Adsorbed H_2O at 2-3 wt%. Estimated 10^4-10^6 MT in dunes, ripples, loose regolith
- H_2O in amorphous component, 3-6 wt%
- Hydrated Phyllosilicates, 2-3 wt%
- Excellent building material for sand bags/radiation protection

Metal and Silica ISRU Resources ISRU01-02

Outcrop 'Link', a matrix-supported conglomerate with relatively high Al and Fe content. Exposures near surface form a natural 'pavement' and ~1 cm sized clasts.
NASA/JPL-Caltech/MSSS

ROI, Latitude, Longitude

- ISRU01 (Al, Si)

-4.253, 137.2109, -3514 m

- ISRU02 (Fe)

Yellowknife Bay

-4.58951574, 137.44909593, -4520.029 m

- ISRU01 rocks on average have ~12 wt% Al and ~55-60 wt% Si. ISRU02 rocks, ~18 wt% Fe.
- ISRU1
  - **300 kg/m^3 Al**
  - **1375-1500 kg/m^3 Si**
- ISRU2
  - **450 kg/m^3 Fe**